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SCRANTON, PA.

Volume III

SURVEYING RAILROAD LOCATION

LAND SURVEYING RAILROAD CONSTRUCTION

MAPPING TRACK WORK

RAILROAD STRUCTURES

WITH PRACTICAL QUESTIONS AND EXAMPLES

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CONTENTS.

SURVEYING.

GEOMETRY.

1180. If two triangles have two sides and the included angle of the one equal to two sides and the included angle of the other, the triangles are equal in all their parts. Thus, in the two triangles *A B C* and *D E F*, Fig. 236, if the side *A B* is equal to the side *D E*; the side *B C* to the side *E F*, and the angle *B* to the angle *E*, the triangles are equal in every respect.

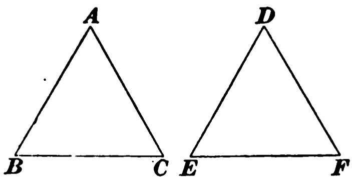


FIG. 236.

1181. If a straight line, *A B*, Fig. 237, intersects two parallel straight lines, *C D* and *E F*, it is called a **secant** with respect to them, and the eight angles formed about the points of intersection have different names applied to them with respect to each other, as follows:

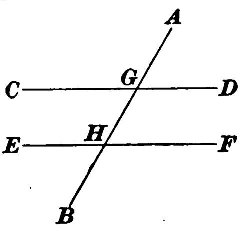


FIG. 237.

First—**Interior angles on the same side** are those which lie on the same side of the secant and *within* the other two lines. Thus, in Fig. 237, *H G D* and *G H F* are interior angles on the same side.

Second—**Exterior angles on the same side** are those which lie on the same side of the secant but *without* the other two lines. Thus, *A G D* and *F H B* are exterior angles on the same side.

Third—**Alternate interior angles** are those which lie on opposite sides of the secant and *within* the other two lines. Thus, *C G H* and *G H F* are alternate interior angles.

Fourth—**Alternate exterior angles** are those which lie on opposite sides of the secant and *without* the other two lines. Thus, $A\ G\ C$ and $F\ H\ B$ are alternate exterior angles.

Fifth—**Opposite exterior and interior angles** are those which lie on the same side of the secant, the one *within* and the other *without* the other two lines. Thus, $A\ G\ D$ and $G\ H\ F$ are opposite exterior and interior angles.

1182. If a straight line intersects two parallel lines, the sum of the *interior* angles on the same side is equal to two right angles, and the sum of the *exterior* angles on the same side is also equal to two right angles. Thus, in Fig. 237, the interior angles $D\ G\ H$ and $F\ H\ G$ are together equal to two right angles, and the exterior angles $D\ G\ A$ and $F\ H\ B$ are together equal to two right angles.

1183. If a line intersects two parallel straight lines, the alternate interior angles are equal to each other, and the alternate exterior angles are also equal to each other. Thus, in Fig. 237, the angle $C\ G\ H$ is equal to $F\ H\ G$, and angle $C\ G\ A$ is equal to $F\ H\ B$.

1184. The **complement** of an angle is the difference between that angle and a right angle. Thus, in Fig. 238, $A\ B\ E$ is the complement of $D\ B\ E$.

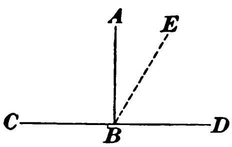


FIG. 238.

1185. The **supplement** of an angle is the difference between that angle and two right angles. Thus, $C\ B\ E$ is the supplement of $D\ B\ E$.

1186. In any triangle, a line drawn parallel to one of the sides divides the other sides proportionally. Thus, in the triangle $A\ B\ C$, Fig. 239, the line $D\ E$ drawn parallel to $B\ C$ divides the sides $A\ B$ and $A\ C$ proportionally; that is,

$$A B : A D :: A C : A E;$$
$$A D : D B :: A E : E C, \text{ and}$$
$$A B : D B :: A C : E C.$$

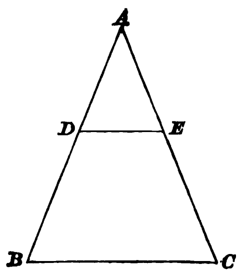


FIG. 239.

1187. Polygons are **similar** when they are mutually equiangular and have their homologous sides proportional.

In similar polygons, any points, lines, or angles similarly situated in each are called **homologous.** The ratio of a side of one polygon to its homologous side in another is called the **ratio of similitude** of the polygons.

1188. Triangles which are mutually equiangular are similar, and their areas are to each other as the squares of their homologous sides.

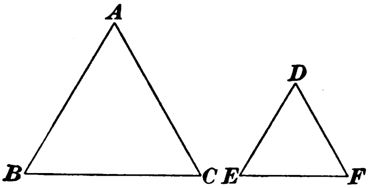


FIG. 240.

Thus, in the triangles $A\,B\,C$ and $D\,E\,F$, Fig. 240, if the angle A is equal to the angle D; the angle B to the angle E, and the angle C to the angle F, the triangles are similar, and their areas are to each other as the squares of their homologous sides.

For example, if $B\,C = 80$ feet, $E\,F = 50$ feet, and the area of the triangle $A\,B\,C = 1{,}600$ sq. ft., then

$$80^2 : 50^2 :: 1{,}600 : \text{area of } D\,E\,F, \text{ or}$$
$$6{,}400 : 2{,}500 :: 1{,}600 : 625 \text{ sq. ft.}$$

Hence, area of $D\,E\,F$ is 625 sq. ft.

1189. The areas of *similar* polygons are to each other as the squares of their homologous sides.

Thus, if the area of a regular hexagon with a side of 10 inches is 259.809 sq. in., the area of a similar hexagon whose side is 15 inches may be found as follows:

$$10^2 : 15^2 :: 259.809 : \text{area required, or}$$
$$100 : 225 :: 259.809 : 584.57 \text{ sq. in.}$$

1190. The circumferences of circles are to each other as their diameters, and their areas are to each other as the squares of their diameters.

Thus, if the circumference of a circle 12 inches in diameter is 37.7 inches, the circumference of a circle of 18 inches diameter may be found by proportion. Thus,

$$12 : 18 :: 37.7 : 56.55 \text{ in., the circumference required.}$$

Again, if the area of a circle of 12 inches diameter is 113.098 sq. in., the area of a circle of 18 inches diameter may be found as follows:

$$12^2 : 18^2 :: 113.098 : \text{area required, or}$$

$$144 : 324 :: 113.098 : 254.47 \text{ sq. in.}$$

1191. An angle formed by a tangent and a chord meeting at the point of contact is measured by half the included arc.

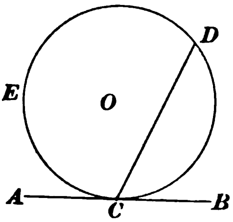


FIG. 241.

Thus, in Fig. 241, the angle $A\ C\ D$ formed by the meeting of the tangent $A\ B$ and the chord $C\ D$ is measured by half the arc $C\ E\ D$. Similarly, the angle $B\ C\ D$ is measured by half the arc $C\ D$.

1192. Two tangents to a circle drawn from any point are equal, and if a chord be drawn joining these tangent points, the angles between the chord and the tangents are equal.

Thus, in Fig. 242, the two tangents $A\ B$ and $A\ C$ drawn to the circle from the point A are equal, and the angles $A\ B\ C$ and $A\ C\ B$, formed by the chord and tangents, are equal to each other.

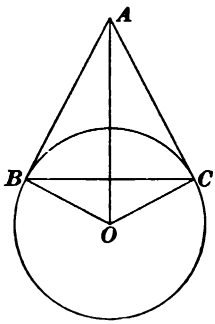


FIG. 242.

1193. In the same or equal circles equal chords subtend equal angles at the center and also at the circumference.

Thus, in Fig. 243, the angles $A\ O\ B$, $B\ O\ C$, and $C\ O\ D$ subtended by the equal chords $A\ B$, $B\ C$, and $C\ D$ are equal to each other.

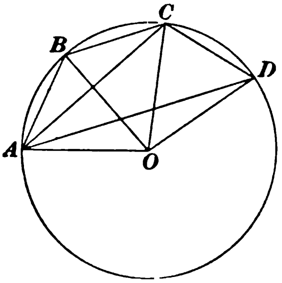


FIG. 243.

Again, the angles $B\ A\ C$ and $C\ A\ D$ are also equal to each other.

1194. In Fig. 244, let $A\ B\ C$ be any triangle. If one of the sides, as $A\ C$, is prolonged, the angle $B\ C\ D$ included between the

side thus prolonged and the other side $B\ C$ of the triangle, which meets $A\ C$ at C, is called an **exterior angle.** The two remaining angles A and B of the triangle, which are opposite to the angle C, are called **opposite interior angles.** In any triangle, an exterior angle is equal to the sum of the two opposite interior angles; that is, in the above figure, the exterior angle $B\ C\ D$ is equal to the sum of the two opposite interior angles, A and B.

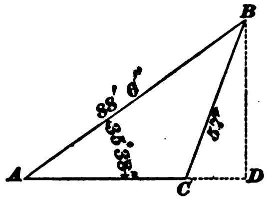


FIG. 244.

1195. PROBLEM.—Having given one of the angles of a triangle, one of the including sides, and the difference of the other two sides, to construct it.

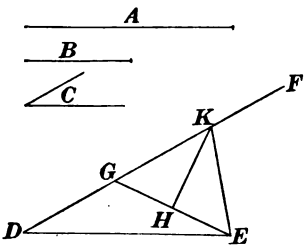


FIG. 245.

Let C, Fig. 245, be the given angle, A the given side, and B the difference of the other sides. Draw $D\ E$ equal to the given side A; at D make the angle $E\ D\ F$ equal to the given angle C; on $D\ F$ lay off $D\ G$ equal to the given difference B. Join $E\ G$. At the middle point H of $E\ G$ erect a perpendicular cutting $D\ F$ in K. Draw $K\ E$. $D\ E\ K$ is the required triangle.

COMPASS SURVEYING.

1196. The Compass.—The **surveyor's compass** consists of the magnetic needle, the case in which it is enclosed, and the support on which it is placed when ready for use.

1197. The Magnetic Needle.—The **magnetic needle** is a slender bar of steel, five or six inches in length, strongly magnetized, and mounted upon a finely pointed pivot on which it freely turns, always pointing in the same

direction, viz.: the north and south line, or, as it is called, the **magnetic meridan.**

1198. North and South Ends of Needle.—Owing to the earth's attraction, the north end of the needle **dips,** that is, it is drawn downward from a horizontal position, while the south end is correspondingly raised. To prevent this dipping, several coils of platinum wire are wound around the south end of the needle (see Fig. 246), keeping it perfectly balanced upon its pivot and permitting entire freedom of movement. These coils of wire at once indicate to the observer which is the north end and which is the south end of the needle.

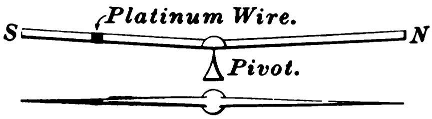


FIG. 246.

1199. The Sights.—At either end of a line passing through the needle pivot is a **sight,** which consists of an upright bar of brass *A* and *B*. (See Fig. 247.) Narrow vertical slits, with holes at their top and bottom, divide this bar, as shown at *C* and *D*. These arrangements enable the observer to train the line of sight upon any desired object.

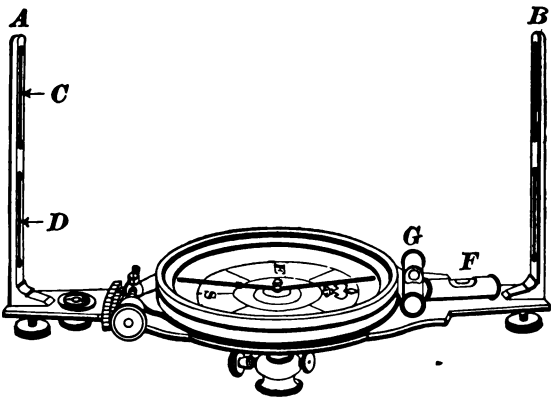


FIG. 247.

1200. The Divided Circle.—The compass box contains a graduated circle divided to half degrees, at the center of which is the pivot supporting the needle. The degrees are numbered from 0° to 90° both ways from the points where a line drawn through the slits would cut the circle.

1201. Lettering.—The lettering of the surveyor's compass is at first confusing to those learning its use. A person standing with his back to the south and facing the north will have the east on his right hand and the west on his left. These latter directions, viz., the east and the west, are reversed in the lettering of the compass. The reasons for this apparent error are explained in the following figures:

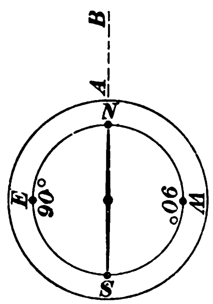


FIG. 248.

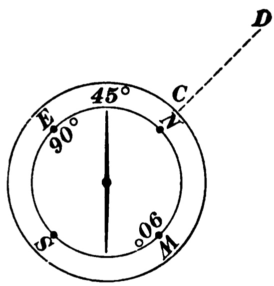


FIG. 249.

Suppose the needle and compass are pointing due north and south in the direction of the line *A B*, as shown in Fig. 248, and the line of survey changes its direction 45° to the right, or east. The magnetic needle will remain motionless, while the sights and the circle to which they are fastened will move until the sights point in the direction *C D*, Fig. 249, and, as the north end of the compass is ahead, the *needle* will read N 45° E, which is the *true direction* being run. If, however, the east and west points of the compass were the actual magnetic directions, i. e., the right hand east and the left hand west, the direction of the line *C D*

would have read N 45° W, which would be the reverse of the actual direction.

1202. Levels.—On the compass plate are two small spirit levels *F* and *G*. (See Fig. 247.) They consist of glass tubes, curved slightly upwards and nearly filled with alcohol, leaving a small bubble of air in them. One of these tubes, *F*, is in the line of sight, the other, *G*, is at right angles to it. Their object is to enable the observer to place the compass in a perfectly horizontal position. This is done by so moving the compass as to bring the air bubbles to the centers of the tubes. To prove these bubbles to be in adjustment, proceed as follows: Having brought the bubbles to the centers of the tubes, revolve the compass through 180° or one-half of an entire revolution. If the bubbles remain in the centers of the tubes, they are in adjustment. If they do not so remain, bring them half way back to the middle of the tubes by means of small screws attached to the tubes, and the remainder of the way by moving the plate in the ordinary way, repeating the operation until the bubbles remain in the center of the tubes in every position of the compass.

1203. The Tripod.—The compass is usually supported by a single standard, shod with steel, and called a **Jacob's Staff.** A more perfect support, called a **tripod,** consists of three legs shod with steel and connected at the top so as to move freely. Both Jacob's Staff and tripod are connected with the compass by means of a ball and socket joint, which permits free movement in all directions.

1204. Defects of the Compass.—The compass is not intended for work requiring great accuracy. The direction to which the needle points can not be read with precision, and the perfect freedom of movement of the needle may be prevented by local attraction or by particles of dust adhering to the pivot. An inaccuracy of one-quarter of a degree in reading an angle, i. e., the amount of change in

the direction of two lines, will cause them to separate from each other $1\frac{3}{4}$ feet in a distance of 400 feet.

Suppose the line $A\ B$, Fig. 250, is due east and west, and the line $B\ C$, which is an actual boundary, has a true direction of N 85° E, and suppose the surveyor reads the directions $B\ C$ as N 84° 45′ E. Let $B\ C = 400$ feet, then, the point C, when mapped, will take the position C', which is $1\frac{3}{4}$ feet to the left of C where it should be. Another defect of the compass lies in the fact that the magnetic needle does

FIG. 250.

not always point in the same direction. This direction sometimes changes between sunrise and noon to the amount of one-quarter of a degree. Frequently its direction is changed by *local influence*. A piece of iron on the surface of the ground or a mass of iron ore beneath are frequent disturbing influences.

1205. Taking Bearings.—The **bearing** of a line is the angle which it makes with the direction of the magnetic needle. By the **course** of a line we mean its length and its bearing taken together. To take the bearing of a line, set the compass directly over a point of it, at one extremity, if possible. This may be done by means of a plumb bob suspended from the compass, or, if the compass be mounted on a Jacob's Staff, by firmly planting the staff directly on the line. Then, by means of the air bubbles, bring the compass to a perfectly level position. Let a flagman hold a rod carefully plumbed at another point of the line, preferably the other extremity of it, if he can be distinctly seen. Direct the sights upon this rod and as near the bottom of it as possible. Always keep the same end of the compass ahead; the north end is preferable, as it is readily distinguished by some conspicuous mark, usually a "*fleur de lis*," and always read the same end of the needle, that is, the north end of the needle if the north point of the compass is ahead,

and *vice versa*. Before reading the angle, see that the eye is in the direct line of the needle so as to avoid error which would otherwise result from **parallax,** or apparent change of the position of the needle, due to looking at it obliquely.

The angle is read and recorded by noting, *first*, whether the N or S point of the compass is nearest the end of the needle being read; *second*, the number of degrees to which it points, and *third*, the letter E or W nearest the end of the needle being read.

Let $A\ B$, in Fig. 251, be the direction of the magnetic needle, B being at the north end. Let the sights of the compass be directed along the line $C\ D$. The north point of the compass will be seen to be nearest the north end of the needle which is to be read. The needle which has remained stationary while the sights were being turned to $C\ D$, now points to 45° between the N and E points, and the angle is read north forty-five degrees east (N 45° E).

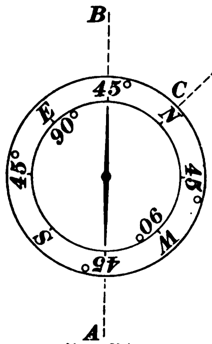


FIG. 251.

1206. Backsights.—A sure test of the accuracy of a bearing is to set up the compass at the other end of the line, i. e., the end first sighted to, and sight to a rod set up at the starting point. This process is called **backsighting.** If the second bearing is the same as the first, the reading is correct. If it is not the same, it shows that there is some disturbing influence at either one or the other end of the line. To determine which of these two bearings is the true one, the compass must be set up at one or more intermediate points, when two or more similar bearings will prove the true one. When a line can not be prolonged by magnetic bearings, on account of local attraction, the true direction is maintained by backsighting.

1207. Declination of the Needle.—The **magnetic meridian** is the direction of the magnetic needle. The **true meridian** is a true north and south line, which, if produced, would pass through the poles of the earth. The **declination of the needle** is the angle which the magnetic meridian and the true meridian make with each other.

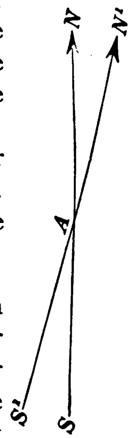


FIG. 252.

In Fig. 252, let $N\ S$ be the true meridian for any given place, and $N^1\ S^1$ the magnetic meridian. The angle $N A N^1$ is the declination of the needle for that place.

1208. The Polar Star.—There is a star in the northern hemisphere known as the North Star or Polaris. It is the extreme star in the row or line of stars forming what is commonly called the handle of the "Little Dipper." This star very nearly coincides with the true north point or pole, being removed only $1\frac{1}{2}°$ from it. It revolves about the true pole, and twice in each revolution it is exactly in the true meridian; that is, in a vertical plane passing through the true pole *P*. See Fig. 253. One may know when the North Star is in the true meridian from the position of another star. This other star is in the handle of the "Big Dipper," or Ursa Major, the one nearest the bowl of the dipper, and is called Alioth. When the North Star is in the true meridian, Alioth will be found directly below it.

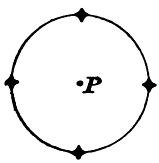


FIG. 253.

TO DETERMINE A TRUE MERIDIAN.

1209. By Observations of the North Star.—The time at which the North Star passes the meridian above the pole for every tenth day of the year is given in published tables, but those occurring in the day time are, of course, of no value with ordinary instruments. The following dates are available in almost every latitude of the United States:

TIME OF NORTH STAR PASSING THE MERIDIAN.

Months.	1st Day.	11th Day.	21st Day.
January.......	6:30 P. M.	5:51 P. M.	5:11 P. M.
August.......	4:33 A. M.	3:53 A. M.	3:14 A. M.
September.....	2:31 A. M.	1:52 A. M.	1:12 A. M.
October.......	12:34 A. M.	11:50 P. M.	11:11 P. M.
November.....	10:28 P. M.	9:48 P. M.	9:09 P. M.
December.....	8:30 P. M.	7:50 P. M.	7:11 P. M.

Note from the table the time of passing the meridian, and, also, that it is the upper transit, i. e., above the pole. Select a suitable spot for permanently establishing the meridian line, and set up the transit and sight to Polaris, following it by moving the cross-hairs with the tangent screw. When it is exactly in line with Alioth, the line of sight will be in the true meridian. Points should be fixed immediately, a lamp being used to illuminate the cross-hairs.

1210. Changes in Magnetic Declination.—The magnetic declination is not fixed for any place, but constantly varies, its variations, however, being confined within fixed limits.

1211. To Correct Magnetic Bearings.—The declination at any place being known, the magnetic bearings may readily be reduced to true bearings.

In the Northeastern States, the declination is west; in the Western and Southern States, it is east; hence, the true bearing of a line in a Northeastern State, whose magnetic bearing is N W or S E, will be the sum of the magnetic bearing and the declination. If the magnetic bearing is N E or S W, the true bearing will be the difference of the magnetic bearing and the declination.

EXAMPLES FOR PRACTICE.

1212. Supposing the declination to be 7° west, what will be the true bearings of the following lines :

Magnetic Bearing.		True Bearings.
(1) N 12° 10′ W ?	Ans.	(1) N 19° 10′ W.
(2) N 50° 15′ W ?		(2) N 57° 15′ W.
(3) S 11° 15′ E ?		(3) S 18° 15′ E.
(4) S 38° 10′ E ?		(4) S 45° 10′ E.
(5) N 50° 20′ E ?		(5) N 43° 20′ E.
(6) S 20° 25′ W ?		(6) S 13° 25′ W.
(7) N 87° 30′ W ?		(7) S 85° 30′ W.
(8) N 5° 10′ E ?		(8) N 1° 50′ W.
(9) S 89° 20′ E ?		(9) N 83° 40′ E.
(10) S 3° 10′ W ?		(10) S 3° 50′ E.

1213. By Equal Shadows of the Sun.—On the south side of any level surface set up a flag-pole and plumb it with a plumb bob. Its horizontal projection will be a point as S in Fig. 254. Two or three hours before noon mark the point A, which is the extremity of the shadow cast by the flag-pole. Then, describe an arc $A\ B$ with a radius equal to $S\ A$, the distance from S to the extremity of the shadow. After noon, note the moment when the shadow of the flag-pole touches another point of the arc, as B. Bisect the arc $A\ B$ at N. The line $S\ N$ is a true meridian.

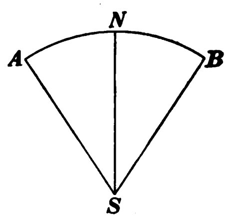


FIG. 254.

FIELD WORK.

1214. The Engineer's Chain.—The engineer's chain is one hundred feet in length, and is composed of one hundred links of steel wire, each one foot in length. Both ends of the chain are fitted with brass handles with swivel movements, and fitted with nuts for taking up any excess in length resulting from continual stretching. At each interval of ten feet is a brass tag with tally points to indicate its distance from the nearest end of the chain. Each tally point counts ten feet. At the middle point of the

chain, the tag is of oval form to prevent confusion in reading the chain.

1215. Danger of Error.—There is much greater danger of error in reading the chain than in reading bearings. The danger arises from the fact that the compassman is usually one of experience, who knows the liability of error, and hence the necessity for care, while chainmen are often inexperienced, and, unfortunately, often careless.

1216. Keeping Chainmen in Line.—When the direction of a line has been given by setting up a flag, it becomes the business of the hind chainman or follower to keep the measurement on a straight line. The head chainman carries a flag which he moves to right or left, at the direction of the hind chainman, until it is in range with the flag towards which the compass is sighted, and this process is repeated at each chain measurement.

In railroad surveying, the line is divided into stations, which are one hundred feet or one chain apart. At each station a stake is driven and marked with a number corresponding to the number of chains which the station is distant from the starting point, which is numbered 0. When the end of a course falls between regular stations, it is called a sub-station, and the stake is marked by the number of the immediately preceding station plus the number of feet from it to the end of the course.

The line *A B*, in Fig. 255, is 650 feet in length. The starting point *A* is numbered *0*; each chain or one hundred

FIG. 255.

feet is marked by a stake with numbers in regular notation. The point *B*, which is fifty feet from station *6*, is marked *6 + 50*.

1217.—The Compass in Railroad Surveys.—The compass is of great value in running preliminary railroad lines, where local attraction is absent or very slight. The numerous delays encountered when running by backsights,

as in transit work, where all obstacles to the line of sight must be cleared, are largely avoided in the use of the compass. The directions of all lines are referred to the magnetic needle, and, in case of an obstruction, such as a tree or a mass of rock, the compass can be quickly moved to the opposite side of the obstacle and the line continued without delay. In case the line produced is a foot or two off the true one, *it is a parallel to it*, and the error is not to be regarded as affecting the accuracy of *preliminary* information.

In the case of transit work, an error in the reading of an angle is a *cumulative* one, and practically destroys the value of the work. In the early days of railroad building, some lines were surveyed and built with the aid of the compass alone, but in America all location and construction depend for their precision upon the transit.

1218. Organization of Party.—A well-organized compass party consists of a chief of party, compassman, two chainmen, one flagman, two or more axmen, if the country be thickly wooded, and one stakeman. If possible, provide stakes of light, well-seasoned wood. For preliminary lines where stakes do no permanent service, pine is best. A convenient size is two feet six inches in length by two inches in width and half an inch in thickness. A strong, active stakeman will carry one hundred of these stakes, besides the ax with which to drive them. Provide both chainmen with marking crayons. The best crayon is of red chalk or German kiel. They are bought in a crude state, but a little work will shape them. They make a deep red mark, which will stand exposure for years. Require chainmen to be always provided with crayons. Instances of their forgetfulness too often occur. Require axmen to keep axes sharp. A dull ax is little better than no ax. Check length of chain with standard steel tape, lengthening or shortening by means explained in Art. **1214.** See that the compass is in perfect adjustment. If the line to be surveyed is of considerable length, a team of horses and driver with a strong spring wagon should be a part of the outfit.

1219. Actual Work.—The party is now prepared to move. The compassman sets up the compass at the starting point, which is marked 0. The chief of party goes ahead with the flagman, who carries a rod called a **flag.** This rod is from eight to twelve feet in length, and is divided into alternate red and white bands, each one foot in length. The flagman sets this flag up at the direction of the chief of party, the compassman sights the instrument to it, and the chainmen commence measuring the distance. The head chainman marks the stakes, and should always keep at least ten stakes marked ahead so as to avoid delay while measuring, and to insure consecutive numbering. Of these he need carry but five, leaving the remaining five with the stakeman. He must also carry a flag eight feet in length, and painted like the one carried by the flagman; this flag is used for "ranging in." As soon as the line is indicated by the head flag, the axmen should fall to work clearing whatever obstacles lie in the way of rapid chaining. By a little attention on their own part and occasional direction from the chainmen, they can keep well on line. At each station, and the moment the hind chainman has put the head chainman in line, the former should carefully note the number of the station at which he stands and call the number to the head chainman, who must answer by repeating the number next in notation. Thus, if the hind chainman stands at Station 25 he must call "Station 25," and the head chainman must reply "Station 26." The chainmen must be required to hold the chain "taut" while measuring, and in as nearly horizontal a position as possible. When the line of measurement rises or falls abruptly, the chainmen must "break the chain," as it is called. The best method of breaking the chain is shown in Fig. 256.

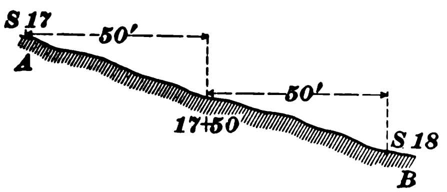


FIG. 256.

Let A B be a sloping surface lying in the line of measurement. The point A is at Station 17. Stretch out the chain to its full length and in proper line. The hind chainman will be at Station 17. The head chainman here takes the chain at the 50-foot tag and raises it until it is practically level. The flag he carries for ranging in will serve for a plumb line to mark the 50-foot point on the ground. The hind chainman then calls the number of his station, 17, the head chainman replying 17 + 50. The former then advances to 17 + 50 and holds the middle tag at the point marked by the rod. The head chainman then advances to the other end of the chain and repeats the operation, reaching Station 18. When the slope is steep, the chain must be broken into smaller sections. It is good practice for the flagman to carry, besides his flag, a number of light stakes at least eight feet in length and some strips of red flannel for **targets.** If the view for the compass is open, as soon as the compass is sighted and the flagman has a signal to that effect, he should replace the flag by one of the stakes with a piece of flannel attached and join the chief of party, who, unless the line is to be produced, has gone ahead to select another point for the flag. As soon as the compassman has recorded the bearing of the line, he should take the compass and walk rapidly to the next station, marked either by the flag or target, and, if in full view of the chainmen, remove the station mark and set up the compass and be prepared to take the next bearing the moment it is indicated by the chief of party. As soon as the chainmen reach the compass and have "taken the plus" from the last full station, the hind chainman calls out the full station and plus, which the head chainman marks on a fresh stake and which the compassman records as the length of the course run. If the same line is to be continued or "produced," the compass is set at the same bearing as the course just run and the chainmen are lined in by the compassman.

1220. Example of the Use of the Compass in Railroad Work.—Suppose C A D in Fig. 257 to be a

railroad in operation, and that it has been decided to run a compass line from the point A along the valley of the stream $X\ Y$ to the point B. The bearing of the tangent $A\ D$ can not be determined by setting up the compass at A, on account of the attraction of the rails. The *direction* of this tangent, however, can be obtained by setting up the compass at A and sighting to the flag held at D. The point A, which is the starting point of the line to be run, is marked *0*. Producing the line $A\ D$ 440 feet, the point E is reached, which has been previously indicated by the chief of party as a proper place for changing the direction of the line. The compass being set up at E, the bearing of the line $A\ E$, which is the line $A\ D$ produced, is found by sighting to A, or, what is preferable, to the point D, if that point can be seen. The number of Station E, viz., $4 + 40$, and the bearing

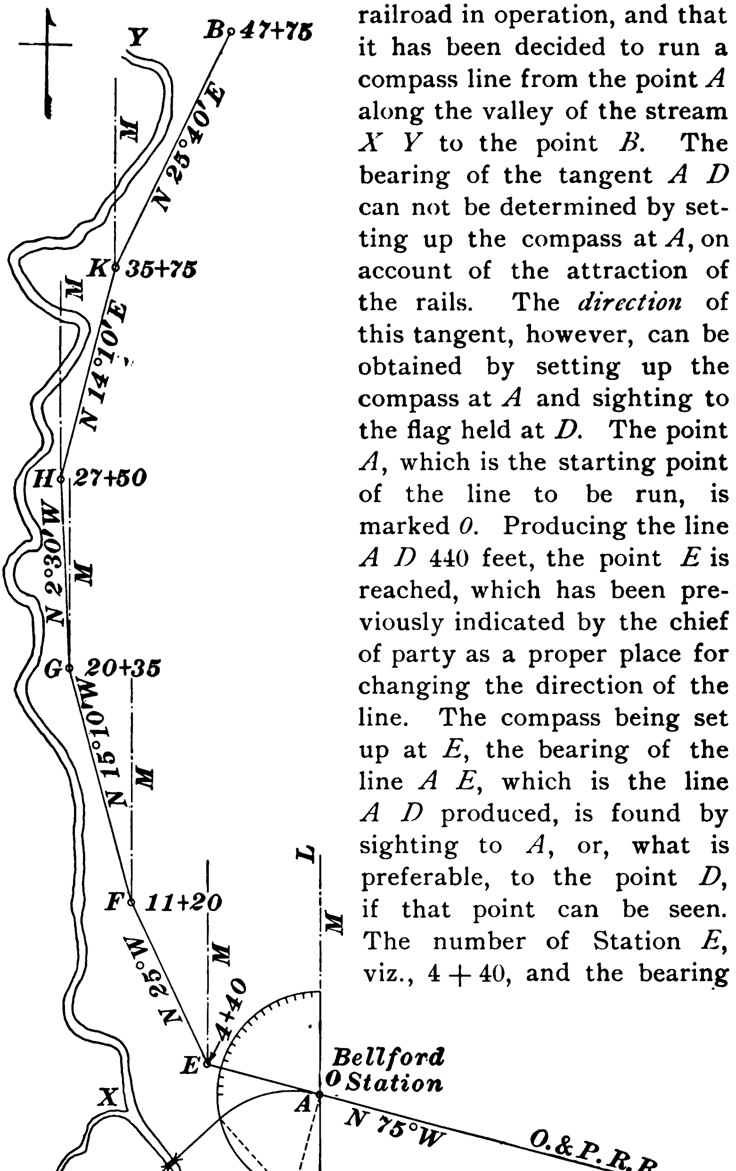


FIG. 257.

of $A E$ are then recorded by the compassman. By this time the chief of party has located the point F, and the flag is in place for sighting. The axmen, if there is work for them to do, are put in line by the head chainman, clearing only so much as would interfere with rapid chaining. The bearing of the line $E F$ being recorded, the compass is moved quickly to F, replacing the target left by the flagman, leveled up, and directed toward the point G, which is either already, or soon will be, located. The chainmen reaching F, its number 11 + 20 is recorded by the compassman, and the instrument sighted to G and the work continued as before.

1221. Form for Keeping Notes.—A plain and convenient form for compass notes is the following, which is a record of the survey platted in Fig. 257: The first column contains the station numbers, the notation running from the bottom to the top of the page. By such an arrangement, the lengths of the courses are found by subtracting the number of the station of one compass point from the number of the station of the next succeeding compass point. Before commencing the plat, the subtractions are made and the lengths of the courses written in red ink between the station numbers.

The second column contains the bearings of the lines. The bearing recorded opposite to a station is the bearing of the course between the given station and the one next above. Thus, the bearing recorded opposite Sta. 0 is N 75° 00′ W, and is the bearing of the line extending from Sta. 0 to Sta. 4 + 40 next above. The length of the course is the difference between 0 and 4 + 40 equal to 440 ft. The bearing recorded opposite to 4 + 40 is N 25° 00′ W. It is the bearing of the line extending from Sta. 4 + 40 to Sta. 11 + 20 next above. Its length is found by subtracting 4 + 40 from 11 + 20 equal to 680 ft., and so on.

In the third column, under the head of remarks, are recorded notes of reference, topography, and any information which may aid in platting or subsequent location.

Station.	Bearing.	Remarks.
47 + 75		End of line
35 + 75	N 25° 40′ E	
27 + 50	N 14° 10′ E	
20 + 35	N 2° 30′ W	Woodland
11 + 20	N 15° 10′ W	
4 + 40	N 25° 00′ W	
0	N 75° 00′ W	Sta. 0 is at P. C. of 14° curve to
		left at Bellford Sta. O. & P. R. R.

1222. Platting.—After a survey has been finished, a drawing is made showing the courses. This drawing is called a **plat,** and the operation of making the plat from the field notes is called **platting.**

Since the direction of every line of a compass survey is referred to the same parallel, viz., the magnetic meridian, the readiest mode of platting such a survey is by the use of the **T** square and protractor. The lines drawn to a **T** square are parallel, and in platting take the direction of the magnetic needle, or meridian.

The line *A B*, described in Art. **1220** and shown in Fig. 257, is platted as follows: The arrow shown in the figure gives the direction of the magnetic meridian. A line *A L*, parallel to this meridian, is drawn through the starting point *A*, and from *A* as a center the line *A E*, whose direction N 75° 00′ W is taken from the field notes kept by the compassman, is laid off with a protractor. The directions west are laid off to the left of the meridian, and those east to the right of the meridian. The course *A E*, being a northwest course, is laid off to the left of the meridian *A L*, as shown in the figure. The length of the line *A E* is then

measured on this line to any convenient scale, usually 200 feet to the inch, and a parallel to the magnetic meridian drawn through *E*, from which the bearing of the line *E F*, viz., N 25° 00′ W, is laid off and platted. The remaining courses are platted in the same manner.

TRANSIT SURVEYING.

THE INSTRUMENT.

1223. The **engineer's transit,** see Fig. 258, is an instrument in which the telescope takes the place of the plain sights of the compass, and in which the angles are read to single minutes by the vernier. A level *C* is attached to the underside of the telescope and a vertical arc *D* is attached to the outside of the left hand standard. A vernier *E* for reading vertical angles is attached to the telescope axis and adjusted by the tangent screw *F*. The standards *G* and *G*, which support the telescope, are fastened to the upper or vernier plate, as is one of the levels *H*, the other being carried by one of the standards at *H′*. The compass circle *K*, which is divided like that of the ordinary compass, is also a part of the upper plate. The vernier plate covers the lower or divided limb, of which only two small arcs can be seen through the openings where the verniers are placed. A

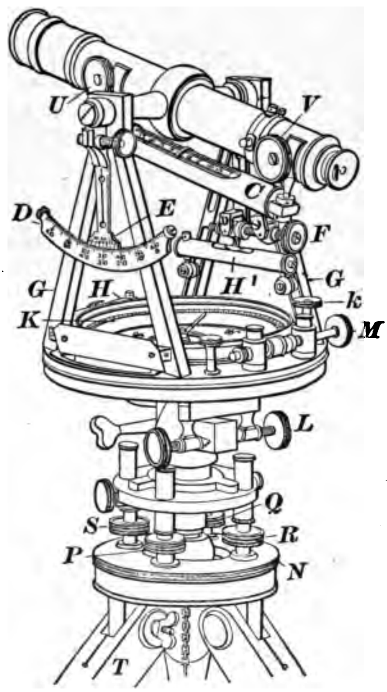


FIG. 258.

screw which clamps the vernier plate to the divided limb is shown at k. Slow motion is given to the upper plate by the tangent screw M, and to the divided limb by the screw L. The transit is fastened to the plate N by a ball and socket joint, and is leveled by means of the screws P, Q, R, and S. It is fastened to the tripod T in a variety of ways, usually screwed to the tripod, the edge of the plate N being milled to aid the operator. The transit is brought to center over a point by means of a plumb bob which is suspended by a loop fastened to the lower part of the transit.

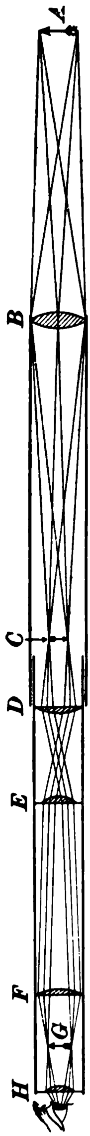


FIG. 259.

1224. The Telescope.—The **telescope** is a combination of lenses placed in a tube and so arranged according to the laws of optics that the image of any object toward which the telescope is directed shall be formed within the tube by the rays of light coming from the object and bent in passing through the object glass. This image is magnified by the eye-piece, which is composed of several lenses. Telescopes are of various kinds, some representing the object erect, i. e., in its natural position, others representing the object inverted.

The telescope shown in Fig. 259 represents the object in an erect position. Rays of light from the object A fall upon the object glass B where they are bent, and, crossing each other, form the image at C in an inverted position. Passing on through the lens D, they are refracted or bent, crossing each other again before reaching the lens at E. Passing through the lens F they form an erect image at G, which is in turn magnified by the eye-piece H.

1225. The Cross-Hairs.—In order that the line of sight may be precisely brought to

bear upon any point of an object within the field of the telescope, two fine lines called **cross-hairs,** or **cross-wires,** are placed with their intersection at the common focus of the object glass and the eye-piece. The intersection of these cross-hairs can be seen through the eye-piece, and seems to be in the same position as that of the image of the distant object.

The line passing through the intersection of the cross-hairs and the optical center of the object glass is called the **line of collimation.**

The cross-hairs are fastened to a thick brass ring placed within the telescope and held in position by **capstan headed screws,** Fig. 260, let into this ring. They are commonly placed at right angles to each other, the one being vertical and the other horizontal. The ring, together with the cross-hairs, can be moved by the capstan headed screws. The cross-hairs are either of platinum wire, drawn very fine, or spider threads. Platinum wire is best, as it is not affected by changes of temperature.

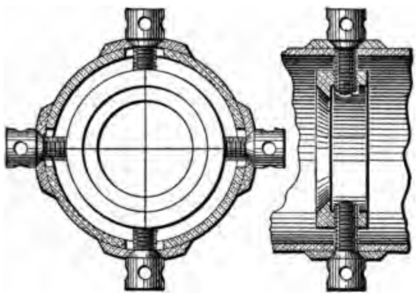


FIG. 260.

1226. Focusing the Telescope.—The movement of the object glass is effected by a milled headed screw *U*, shown in Fig. 258. This screw moves the object glass out or in, according as the object is nearer or further from the instrument. The eye-piece is focused upon the cross-hairs by a similar screw *V*. The cross-hairs are not in proper focus until they appear to be a part of the object looked at, showing no movement, however the position of the eye may be changed.

The telescope is supported upon an axis and so placed that both ends shall be as nearly balanced as possible. The axis

rests on upright legs called the **standards.** The standards are fastened to the upper plate.

1227. The Graduated Circle.—This circle is divided into 360 equal parts or degrees, and each degree is further divided into two or three equal parts. If the degree is divided into two equal parts, each part equals 30′, and if into three equal parts, each part equals 20′. The degrees number from 0 to 360°, and in most instruments there is an inner graduated circle, which numbers each way from 0 to 90°, as on the compass circle. Each tenth degree is numbered; each fifth degree is indicated by a longer line of division, and each degree by a line longer than its subdivisions.

1228. Movements.—When the line of sight is to be brought to bear upon a distant object, the observer turns the telescope in the direction of the object by lightly but firmly grasping the upper plate, one hand on either side of the instrument. The eye is ranged along the top of the telescope, which is turned by the hands until it appears to be in the direct line of the object. The eye is then brought to the eye-piece, and the object glass focused upon the object. The instrument is then clamped, and, by means of either of the tangent screws, the cross-hairs are brought to bear precisely upon any desired point of the object viewed.

1229. The Levels.—Most of the angles measured by the transit are horizontal angles, but whether horizontal or vertical, before an angle can be measured, the plate carrying the graduated circle must be brought to a horizontal position. This is effected by means of two small levels placed on the plate at right angles to each other. Each level consists of a glass tube curved upwards at its middle and nearly filled with alcohol, leaving only space for a bubble of air. They are so placed that when the air bubbles are exactly in the middle of the tubes, the plate upon which they rest will be in a level position. The leveling is

performed by means of four leveling screws. They have milled heads and are arranged in pairs, the line passing through one pair being at right angles to that passing through the other pair.

1230. To Level the Instrument.—Loosen the lower clamp and bring one of the bubble tubes into a parallel to a plane passing through a pair of opposite screws. By turning these screws, the air bubble can be brought exactly to the center of the tube. As the tubes are at right angles to each other, the putting of one in position for leveling adjusts the other for leveling also, and having leveled one tube with one pair of screws, the other tube is leveled with the other pair.

1231. The Vernier.—A **vernier** is a contrivance for measuring smaller portions of space than those into which

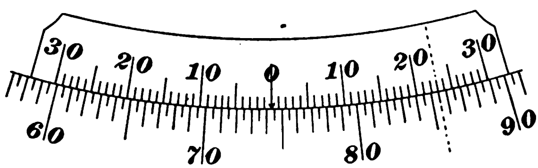


FIG. 261.

a line is actually divided. The divided circle of the transit is graduated to half degrees, or 30′. The graduations on the verniers run in both directions from its zero mark, making two distinct verniers, one for reading angles turned to the right, and the other for reading those turned to the left. Each vernier is divided into 30 equal spaces, which are together equivalent to 29 spaces on the divided circle; hence, each space on the vernier is equal to 29′, and the vernier is described as reading to minutes. In reading the vernier, the observer should first note in which direction the graduations of the divided circle run. In Fig. 261 the graduations increase from left to right and extend from 57° to 91°. Next he should note the point where the zero mark of the vernier comes on the divided circle. In Fig. 261, the zero mark comes between 74° and $74\frac{1}{2}$°. Now, as the circle graduations

read from left to right, we read the right-hand vernier and find that the 23d graduation on the vernier coincides with a graduation on the divided circle, and the vernier reads 23′, which we add to 74°, making a reading of 74° 23′, an angle to the *left*. In Fig. 262 the graduations on the circle increase from right to left, and we accordingly read the left-hand vernier. The zero mark of the vernier comes between $67\frac{1}{2}$ and 68°. Reading the vernier, we find that the

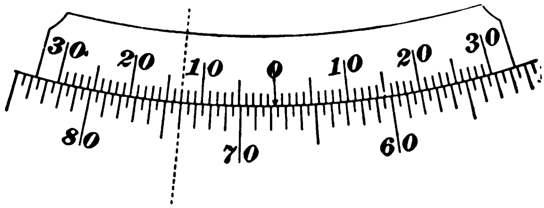


FIG. 262.

13th graduation on the vernier coincides with a graduation on the circle, and the vernier reads 13′. Accordingly, we add to $67\frac{1}{2}$°, the vernier reading of 13′, making a total reading of 67° 43′, an angle to the *right*.

ADJUSTING THE TRANSIT.

1232. The constant use of an instrument tends to disarrange some of its parts, which detracts from the accuracy of its work, without in any way injuring the instrument itself.

The correction of this disarrangement of parts is called making the adjustments.

The transit, when leveled up, will, if in adjustment, fulfil the following conditions, viz.:

1. It will maintain a perfectly **horizontal position** during an **entire revolution.**

2. The line of sight, when directed in **opposite directions,** will be in the **same straight line**; and

3. The line of sight will revolve in a **vertical plane** perpendicular to the **horizontal plane** of revolution.

The adjustments should be made in the order of these three conditions. The best time of the day for making the adjustments, especially in the summer season, is the early morning, before the air has become heated and the sun dazzling.

1233. First Adjustment.—Secure, if possible, an open space where a clear sight may be had for at least 400 feet in both directions from the transit. Plant the feet of the tripod firmly in the ground, and then bring the plate to a horizontal position with the leveling screws. Next turn the vernier plate half way around, i. e., revolve it through an angle of 180°. If the bubbles are in adjustment they will remain stationary in the centers of the tubes. If they do not remain so, but run to either end, bring them half way back to the middle of the tubes by means of the capstan headed screws attached to the tubes, and the rest of the way back by the leveling screws. Then, revolve them again through 180°. Sometimes this adjustment is made by one trial, but it is usually necessary to repeat the operation.

1234. Second Adjustment.—To cause the line of collimation to revolve in a plane :

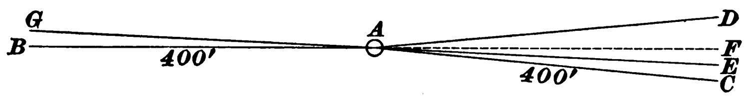


FIG. 263.

Measure from A, where the instrument is stationed (see Fig. 263), 400 feet to the point B, where a pin (or tack, if it can be seen) is fixed.

Carefully direct the line of sight to this point, and **reverse** the telescope, i. e., *turn it on its axis until it points in the opposite direction.* If the line of collimation is "in adjustment," a pin set 400 feet from A, on the opposite side of the instrument from B, will be at F and in the same line as A B; if it is not in adjustment, the pin will be on one side of F, as at D. Turn the *vernier plate* half way around, that is, through 180°, and direct the line of sight again to B.

Reverse the telescope, and the pin will be at C. Carefully measure the distance $C\,D$, and at E, one-fourth of the distance from C to D, set the pin. Move the cross-hairs by means of the capstan headed screws until the vertical hair shall exactly cover the pin at E, being careful to move them in the opposite direction from that in which it would appear they should move. This movement having been made and the telescope reversed, the line of sight will not be at the point B, but at G, a distance from B equal to $C\,E$. Again sight to B, and, reversing, the pin will be at F, in the same line as $A\,B$. It may be necessary to repeat the operation to secure an exact adjustment. If so, take a new set of points, a few inches removed from those first used, to avoid confusion.

1235. Third Adjustment.—To cause the line of collimation to revolve in a vertical plane:

Suspend a plumb bob at as high an elevation as can be readily found; direct the line of sight to the upper end of this line and then, revolving the telescope slowly downwards, see if the intersection of the cross-hairs closely follows this line throughout its length. If it does follow it, the line of collimation revolves in a vertical plane. If it does not, the adjustment may be made as follows: Take a point A, in Fig. 264, on a church spire or some other high object, and sight carefully to it. Depress the telescope until a pin can be set in the ground at its base, as at B. Loosen the clamp and turn the plate through 180° without touching the telescope. Clamp the instrument and sight again to the high point A. Again depress the telescope and set another pin, which it will be found is at some distance from B, as at C. The vertical plane is the line $A\,D$, and it will be seen that the error is doubled. The adjustment is made by raising or lowering one end of the telescope axis by means of a small screw placed in the standard for that purpose.

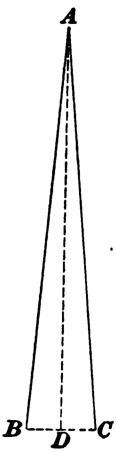


FIG. 264.

DIRECTIONS FOR USING THE TRANSIT.

1236. Care of the Transit.—The transit, though it will bear a lifetime of legitimate service, will not stand neglect or banging. The bearings are delicate and easily marred by particles of dust or sudden blows. Moisture clouds the lenses, and, when combined with dust, is doubly injurious. Little advantage is gained from working in the rain, and, unless the stress of work requires it, both instrument and men are better off under cover. If the instruments should encounter a wetting, carefully wipe the object glass, eye-piece, and verniers with a piece of chamois skin, as moisture soon clouds them so as to prevent further work. As soon as the party returns to office or camp, complete the drying process by thoroughly rubbing with a piece of chamois skin, which every engineering party should carry. When a party rides to and from work, the instruments should be carried in their cases, and they should always be kept in their cases when in the office. The common custom of leaving an instrument on its tripod and standing on a board floor can not be too severely condemned.

1237. Setting Up the Instrument.—As much of the work of an engineering party is suspended while the instrument is being set up, it is highly important to acquire facility in setting it up. The following suggestions will be of use, although practice alone will make one expert.

In setting up a transit, three preliminary conditions should be met as nearly as possible, viz.:

1. The tripod feet should be firmly planted.

2. The plate on which the leveling screws rest should be level; and

3. The plumb bob should be directly over the given point.

The third condition must be met to a nicety, and this is rendered comparatively easy by means of a "shifting head" with which most modern transits are provided. When these three conditions are approximately met, the completion of the operation is quickly performed with the leveling screws.

1238. How to Prolong a Straight Line.—Let $A\ B$, in Fig. 265, be a straight line, and it is required to prolong or produce it 400 feet to C.

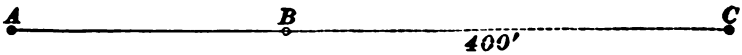


FIG. 265.

The line can be prolonged in two ways—by means of **foresight** and **backsight.**

1. By foresight, set up the transit at A and sight to B; let the chainman measure 400 feet from B in the direction in which the line is to be prolonged. Then, by means of signals, move the flag to right or left until the vertical cross-hair shall exactly divide the flag held at C. Then, the line $B\ C$ will be the prolongation of the line $A\ B$.

2. By backsight, set the transit at B and sight to A. Reverse the telescope, and, having measured 400 feet from B in the opposite direction from A, set the flag at C, then the line $B\ C$ will be the line $A\ B$ produced.

1239. Double Centers.—In prolonging lines, a device known as **double centering** is sometimes used. It is unnecessary when using an instrument that is in proper adjustment, but it is a good check, and a knowledge of the method is valuable.

Let $A\ B$, in Fig. 266, be a given line which it is required to produce 1,000 feet. Set up the transit at B;

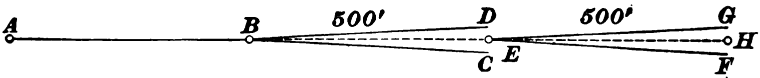


FIG. 266.

backsight to A, and reverse the instrument. Set a point C 500 feet from B. Unclamp the upper plate and revolve the telescope through 180°, backsighting again to A. Reverse the telescope. If the line of sight does not come at C, then the point C is not in line with the points A and B, and the line of sight will be at some point, as D, on the opposite side of the true line. Measure the space $C\ D$ and mark its middle point E. The point E will be in the prolongation of the

line A B. Move the transit to E, and, backsighting to B, determine the point H by the same means used in fixing the point E.

1240. Horizontal Angles and Their Measurement.—A horizontal angle is one the boundary lines of which lie in the same horizontal plane. Let A, B, and C, in Fig. 267, be three points, and let it be required to find the horizontal angle formed by the lines A B and A C joining these points. Set up the instruments precisely over the angular point A, and carefully level it. Set the vernier at zero, and place the flag at B and at C. Sight the flag at B and set the lower clamp. Then, by means of the lower tangent screw cause the vertical cross-hair to exactly bisect the flag at B. Loosen the upper clamp. With a hand on either standard, turn the telescope in the same direction as that of the hands of a watch until the flag at C is covered or nearly covered by the vertical cross-hair. Clamp the upper plate and with the upper tangent screw bring the line of sight exactly on the flag at C. The arc of the graduated circle traversed by the zero point of the vernier will be the measure of the angle B A C, equal to 143° 30′. The points A, B, and C are not necessarily in the same horizontal plane, but the level plate of the instrument projects them into the horizontal plane in which it revolves.

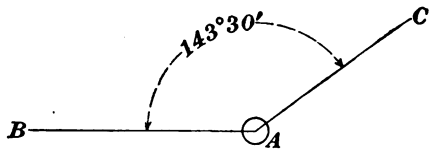


FIG. 267.

1241. A Deflected Line.—A deflected line, or "angle line," is a consecutive series of lines and angles. The direction of each line is referred to the line immediately preceding it, which preceding line is, in imagination, produced, and the angle measured between it and the next line actually run. The angles are recorded R^t or L^t, according as they are turned to the right or left of the prolongation of the immediately preceding line. An example of a deflected line

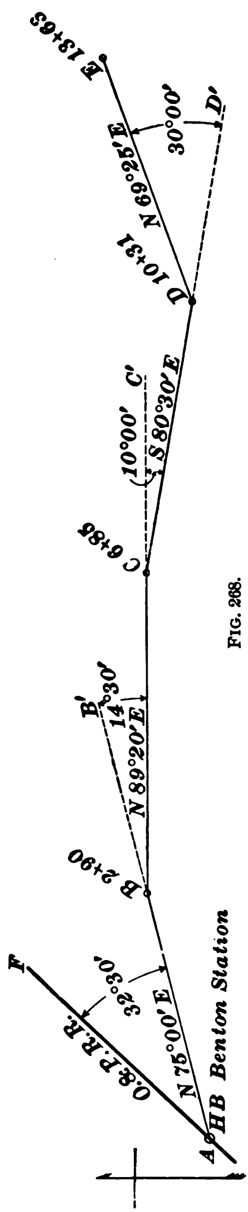


Fig. 268.

is shown in Fig. 268. Here the starting point, A, of the line is a point in the *head-block* of the switch at Benton Station, O. & P. R. R. The point A is, of course, in the center line of the track.

Set up the transit at A with the vernier at zero. Sight to a flag held at F on the center line of the track, O. & P. R. R. Loosen the vernier clamp, and turn the telescope sight to a flag held at B, the next point on the angle line; clamp the vernier, and, by means of the tangent screw, accurately sight to the flag held at B; the angle reads 32° 30′, and is recorded R^t 32° 30′, with a sketch showing the connection in which the term head-block is designated by the abbreviation $H.\ B.$ The bearing of the line $A\ B$ can not be taken at A on account of the attraction of the rails. The instrument is now moved to B, the vernier set at zero and backsighted to A; the bearing of $A\ B$, N 75° 00′ E, is taken, and the number of station B, 2 + 90, together with the bearing of $A\ B$, recorded. The telescope is then reversed, pointing in the direction $B\ B'$. The point C being determined, the upper clamp is loosened and the telescope turned to the right and sighted to C. The reading of the angle is found to be 14° 30′, and recorded R^t 14° 30′. It measures the angle $B'\ B\ C$. The bearing of the line $B\ C$, N 89° 20′ E, is then recorded. The instrument is next set

up at C, the vernier set at zero, backsighted to B, and then reversed; the deflection to D, R' 10° 00′, is then read and recorded, together with the number of the station at C, 6 + 85. This deflection measures the angle $C'\ C\ D$, and

Station.	*Deflection.*	*Mag. Bearing.*	*Ded. Bearing.*	*Remarks.*	
13+63				*End of Line.*	
10+31	*L^r 30°00′*	*N. 69°25′ E.*	*N. 69°30′ E.*		
6+85	*R^r 10°00′*	*S. 80°30′ E.*	*S. 80°30′ E.*		
2+90	*R^r 14°30′*	*N. 89°20′ E.*	*N. 89°30′ E.*		*H. R. of Switch*
0		*N. 75°00′ E.*		*Sta. 0*	*at Benton Sta.*

gives the direction of the line $C\ D$. A good form of notes for such a survey is that given above.

1242. Checking Angles by the Needle.—In spite of the greatest care, errors in the reading and recording of angles will occur. The best check to such errors is the magnetic needle. And though it is not an exact check, owing to the lack of precision in reading the needle and to local attraction, yet it is the only reliable one, and in universal use.

In Fig. 269, we have an example of the use of the needle

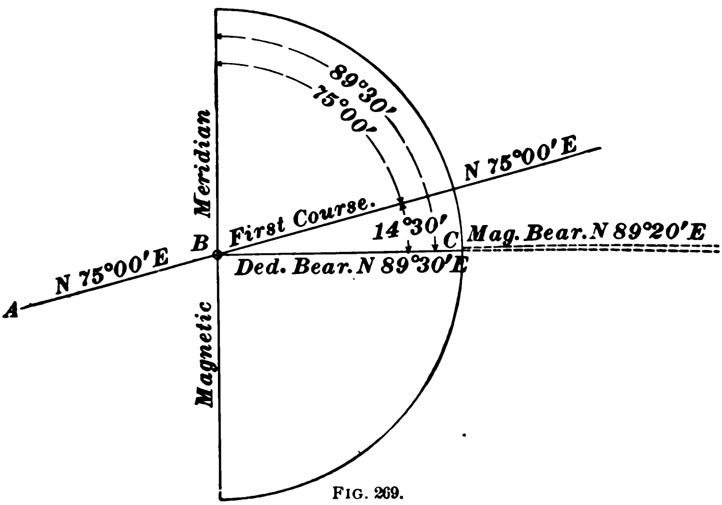


FIG. 269.

in checking angles. The bearing of the line $A\ B$, which corresponds to $A\ B$ in Fig. 268, is N 75° 00′ E, and is assumed to be correct. The bearing of the line $B\ C$, as read from the needle, is N. 89° 20′ E. Its **deduced** or **calculated bearing** is obtained as follows: To the bearing of the line $A\ B$, N 75° 00′ E, we add the R^t deflection 14° 30′; the sum is 89° 30′, which is recorded in the column headed Ded. Bearing. (See Art. **1241.**) The deduced bearing, it will be seen, is ten minutes greater than the magnetic bearing as read from the needle and recorded in the column headed Mag. Bearing. Had the deflection angle been recorded L^t instead of R^t, the deduced bearing would have been the difference between 75° 00′ and 14° 30′, which is 60° 30′, and would be recorded N 60° 30′ E. The magnetic bearing being N 89° 20′ E would have at once revealed the error. The confusion of the directions R^t and L^t is the commonest source of error in recording deflections, though sometimes a mistake of ten degrees is made in reading the vernier. It is a wise precaution to read both angle and bearing after they are recorded and compare them with the recorded readings.

TRIANGULATION.

1243. Simple Triangulation.—**Triangulation** is an application of the principles of trigonometry to the measurement of inaccessible lines and angles. A common occasion for the use of trigonometry is illustrated in Fig. 270, where the line of survey crosses a stream too wide and deep for actual measurement. Set two points A and B on line, one on

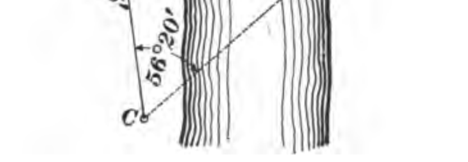


FIG. 270.

each side of the stream. Estimate roughly the distance $A\ B$. Suppose the estimate is 425 feet. Set another point C, making the distance $A\ C$ equal to the estimated distance $A\ B = 425$ feet. Set the transit at A and measure the angle $B\ A\ C =$ say $79°\ 00'$. Next set up at the point C and measure the angle $A\ C\ B =$ say $56°\ 20'$. The angle $A\ B\ C$ is then determined by subtracting the sum of the angles A and C from 180°; thus, $79°\ 00' + 56°\ 20' = 135°\ 20'$. $180°\ 00' - 135°\ 20' = 44°\ 40' =$ the angle $A\ B\ C$. We now have a side and three angles of a triangle given, to find the other two sides $A\ B$ and $C\ B$. These sides may be easily found by the methods given for the solution of triangles (see Arts. **759**, etc.) by drawing a line from the vertex of one of the angles A or C so as to divide the triangle $A\ B\ C$ into two right-angled triangles. A simpler and easier method, however, is the following: In higher works on trigonometry, it has been demonstrated that, *in any triangle, the sines of the angles are proportional to the lengths of the sides opposite to them.* In other words, $\sin A : \sin B :: B\ C : A\ C$; or, $\sin A : \sin C :: B\ C : A\ B$, and $\sin B : \sin C :: A\ C : A\ B$.

Hence, we have $\sin 44°\ 40' : \sin 56°\ 20' :: 425 :$ side $A\ B$.

$$\sin 56°\ 20' = .83228;$$
$$.83228 \times 425 = 353.719;$$
$$\sin 44°\ 40' = .70298;$$
$$353.719 \div .70298 = 503.17 \text{ ft.} = \text{side } A\ B.$$

Adding this distance to $76 + 15$, the station of the point A, we have $81 + 18.17$, the station at B.

Another and frequent occasion for the use of trigonometry is the following: Two tangents, $A\ B$ and $C\ D$, Fig. 271, which are to be united by a curve, meet at some inaccessible point E. Tangents (which will be more fully described later on) are the straight portions of a line of railroad. The angle $C\ E\ F$, which the tangents make with each other, and the distances $B\ E$ and $C\ E$ are required. Two points A and B of the tangent $A\ B$, and two points C and D of the tangent $C\ D$, being carefully located, set the transit at B, and,

backsighting to A, measure the angle $E\ B\ C = 21°\ 45'$; set up at C, and backsighting to D, measure the angle $E\ C\ B = 21°\ 25'$. Measure the side $B\ C = 304.2$ ft.

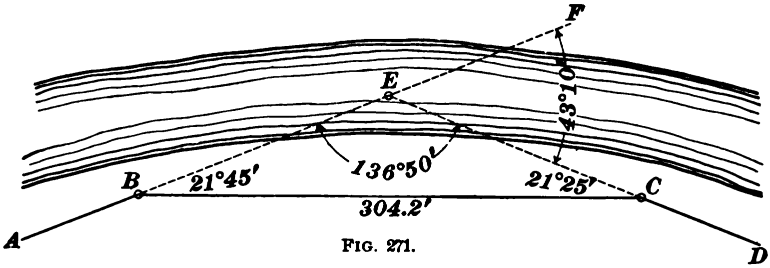


FIG. 271.

Angle $C\ E\ F$ being exterior to the triangle $E\ B\ C$ is equal (see Art. **1194**) to the sum of $E\ B\ C$ and $E\ C\ B = 21°\ 45' + 21°\ 25' = 43°\ 10'$. The angle $B\ E\ C = 180° - C\ E\ F = 136°\ 50'$.

From the principle stated we have sin 136° 50′ : sin 21° 45′ :: 304.2 ft. : side $C\ E$.

Sin 21° 45′ = .37056;
.37056 × 304.2 = 112.724352;
sin 136° 50′ = .68412;
side $C\ E$ = 112.724352 ÷ .68412 = 164.77 ft.

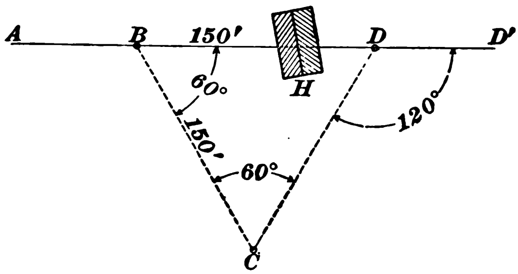


FIG. 272.

Again, we find $B\ E$ by the following proportion:

Sin 136° 50′ : sin 21° 25′ :: 304.2 : side $B\ E$;
sin 21° 25′ = .36515;
.36515 × 304.2 = 111.07863;
sin 136° 50′ = .68412;
side $B\ E$ = 111.07863 ÷ .68412 = 162.36 ft.

A building H, Fig. 272, lies directly in the path of the line $A\ B$ which must be produced beyond H. Set a plug at B and then turn an angle $D\ B\ C = 60°$. Set a plug at C in the line $B\ C$, at a suitable distance from B, say 150 feet. Set up at C, and turn an angle $B\ C\ D = 60°$, and set a plug at D, 150 ft. from C. The point D will be in the prolongation of $A\ B$. Then, set up at D and backsighting to C, turn the angle $C\ D\ D' = 120°$. $D\ D'$ will be the line required, and the distance $B\ D$ will be 150 feet, since $B\ C\ D$ is an equilateral triangle.

$A\ B$ and $C\ D$, Fig. 273, are tangents intersecting at some

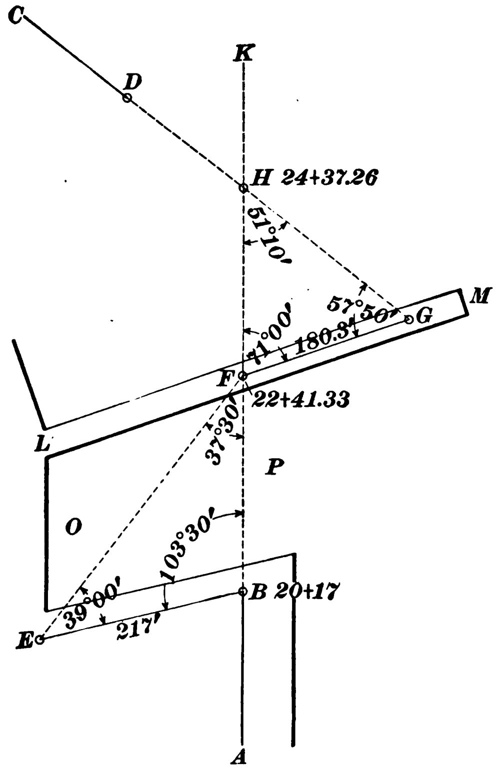


FIG. 273.

inaccessible point H. The line $A\ B$ crosses a dock $O\ P$, too

wide for direct measurement, and the wharf $L\ M$. F is a point on the line $A\ B$ at the wharf crossing. It is required to find the distance $B\ H$ and the angle $F\ H\ G$. At B, an angle of 103° 30′ is turned to the left and the point E set 217′ from B = to the estimated distance $B\ F$. Setting up at E, the angle $B\ E\ F$ is found to be 39° 00′. Whence, we find the angle $B\ F\ E = 180° - (103°\ 30' + 39°) = 37°\ 30'$. From the above principle we have sin 37° 30′ : sin 39° 00′ :: 217 ft. : side $B\ F$.

$$\text{Sin } 39°\ 00' = .62932;$$
$$.62932 \times 217 = 136.56244;$$
$$\sin 37°\ 30' = .60876;$$
$$\text{side } B\ F = 136.56244 \div .60876 = 224.33 \text{ ft.}$$

Whence, we find the station of F to be $20 + 17 + 224.33 = 22 + 41.33$. Set up at F and turn an angle $H\ F\ G = 71°\ 00'$, and set up at a point G where the line $C\ D$ prolonged intersects $F\ G$. Measure the angle $F\ G\ H = 57°\ 50'$, and the side $F\ G = 180.3'$. The angle $F\ H\ G = 180° - (71° + 57°\ 50') = 51°\ 10'$. From the same principle as before we have sin 51° 10′ : sin 57° 50′ :: 180.3′ : side $F\ H$.

$$\text{Sin } 57°\ 50' = .84650;$$
$$.84650 \times 180.3 = 152.62395;$$
$$\sin 51°\ 10' = .77897;$$
$$\text{side } F\ H = 152.62395 \div .77897 = 195.93 \text{ ft.};$$

whence, we find the station of H to be $24 + 37.26$.

1244. Vertical Angles.—A **vertical angle** is an angle formed by two intersecting lines lying in the same vertical plane, one of which is horizontal. If the lines $A\ B$ and $A\ C$, Fig. 274, lying in the vertical plane $D\ E\ F\ G$, meet at the point A, and the line $A\ B$ is horizontal, the angle $C\ A\ B$ is a *vertical angle*, and is measured by the arc $B\ C$.

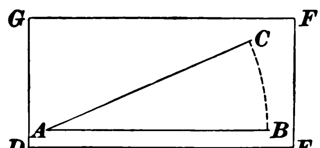


FIG. 274.

1245. Intersection of Tangents.—Let $A\ B$ and $C\ D$, Fig. 275, be tangents whose point of intersection is to

be determined and the angle which they make with each other to be measured. First set up a flag or stake at *B* and another at *A*, or some other point in the line *A B*. Set up the transit at *C*, backsighting to *D*. Reverse the instrument. Have a flagman hold a rod in the line *C D*, at the same time putting himself in range with the stakes at *A* and *B*. With a little practice he can nearly determine the intersection *I* of the two lines. Then drive two stakes *K* and *L* firmly in the line *C D*, one on each side of the point *I*. Their distance from the point *I* to be determined by the obtuseness

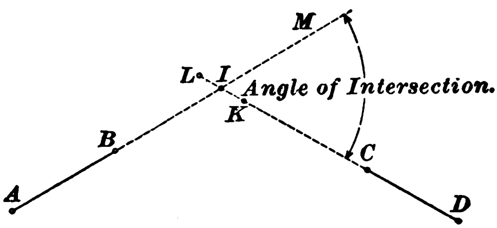


FIG. 275.

of the angle *A I D*. Carefully center these stakes, driving a tack half its length in each center. Stretch a cord between these tacks. Next set up the instrument at *B*, backsighting to *A*. Reversing the telescope, set a flag at *I*, which will be the intersection of the line *A B* prolonged with *L D*. Drive a stake flush with the ground at *I* and drive a tack in this stake where the prolongation of *A B* crosses the cord connecting the stakes at *K* and *L*. The point *I* is the intersection of the tangents *A B* and *C D*. The external angle *C I M*, formed by the intersecting tangents, is called the **angle of intersection.**

CURVES.

1246. A line of railroad consists of a series of straight lines and curves. In general, the straight lines, or, more properly, the tangents, are first located and then they are united by curves best fitting the ground lying between the tangents. There are certain limits of curvature prescribed for all roads, which must not be exceeded. These limits

will depend upon conditions to be explained later. Railroad curves are circular and are divided into *simple*, *compound*, and *reverse* curves.

A **simple curve** has but one radius, as *A B* in Fig. 276, whose radius is *A C*.

A **compound curve**, shown in Fig. 277, is a continuous

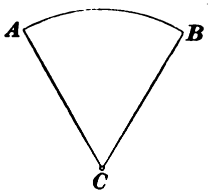


FIG. 276.

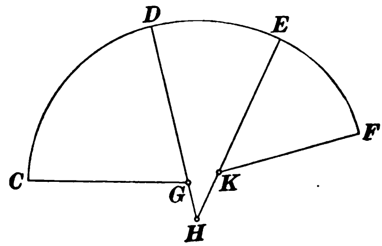


FIG. 277.

curve of two or more arcs of different radii, as *C D E F*, which is composed of the arcs *C D*, *D E*, and *E F*, whose respective radii are *G C*, *H D*, and *K E*.

A **reverse curve**, Fig. 278, is a continuous curve composed of two arcs *L M* and *M N* of the same or of different radii described in the opposite directions, and having a common point *M*, called the point of reversal. Reverse curves, though common in the early days of railroad building in the United States, are now condemned for roads of standard gauge, and only admitted for narrow-gauge roads, when cheapness of construction is the first requirement.

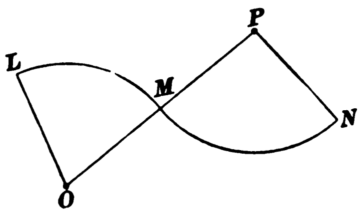


FIG. 278.

1247. Geometry of the Circle.—Before attempting to lay out curves, a knowledge of geometry relating to the circle must be mastered. The following propositions are of special importance:

1. A tangent to a circle is perpendicular to the radius drawn through its tangent point. Thus, *A E*, Fig. 279, is perpendicular to *B O*, and *C E* is perpendicular to *C O*.

2. Two tangents drawn to a circle from any point are equal, and if a chord be drawn joining these points, the angles between the chord and the tangents are equal. Thus, $B\,E$ and $C\,E$ are equal, and the angles $E\,B\,C$ and $E\,C\,B$ are equal.

3. An acute angle between a tangent and a chord is equal to half the central angle subtended by the same chord; thus, the angle $E\,B\,C = E\,C\,B =$ one-half $B\,O\,C$.

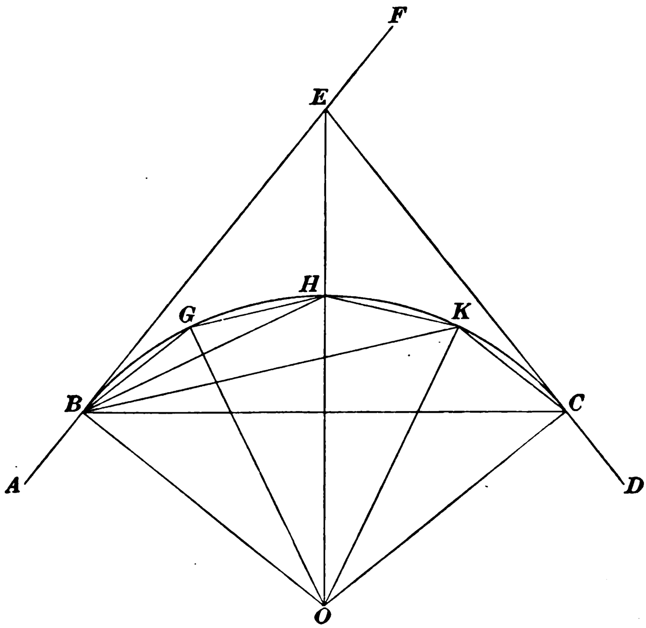


FIG. 279.

4. An acute angle subtended by a chord, and having its vertex in the circumference of a circle, is equal to half the central angle subtended by the same chord. Thus, the angle $E\,B\,G$, whose vertex B is in the circumference and subtended by the chord $B\,G$, is equal to half the central angle $B\,O\,G$, subtended by the same chord $B\,G$.

5. Equal chords subtend equal angles at the center of a circle and also at the circumference, if the angles are

inscribed in similar segments. Thus, if *B G*, *G H*, *H K*, and *K C* are equal, $B\ O\ G = G\ O\ H$ and $G\ B\ H = H\ B\ K$.

6. The angle of intersection of two tangents equals the central angle subtended by the chord uniting the tangent points. Thus, the angle $C\ E\ F = B\ O\ C$.

1248. Deflection Angles.—When two lines meet in the same plane, they are said to form an angle, and the point of meeting is called the **angular point.** The rate of divergence or deflection of the two lines from their common or angular point determines the size of the angle. The unit of angular measurement is the *degree*, equal to $\frac{1}{360}$ part of a circle. Two lines forming an angle of one degree with each other will, at a distance of one hundred feet from the angular point, deflect or diverge 1.745 feet.

In Fig. 280, the lines *A B* and *A C*, meeting at the point *A*, are supposed to form an angle of 1°, and the angle *B A C* is measured by the arc *B C*, described with the radius *A B*,

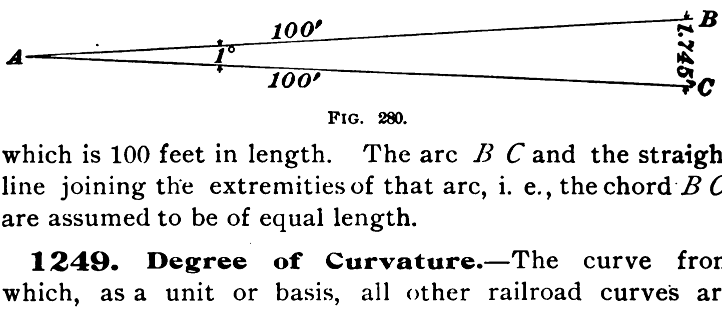


FIG. 280.

which is 100 feet in length. The arc *B C* and the straight line joining the extremities of that arc, i. e., the chord *B C*, are assumed to be of equal length.

1249. Degree of Curvature.—The curve from which, as a unit or basis, all other railroad curves are deduced, is called a **one-degree curve.** It is the circumference of a circle whose radius is 5,730 feet, or, more exactly, 5,729.65 feet, in length. Two radii forming an angle of one degree at the center of a one-degree curve will subtend a chord of 100 feet at its circumference. The arc subtended by this chord of 100 feet is assumed to be of the same length as the chord.

In Fig. 281, let *A B* and *A C* be radii 5,729.65 feet in length, forming an angle of 1° at the center *A*; then the arc *B C* subtended by these radii will be 100 feet in length. The curve *B C* is called a 1° curve. If, from the point *O* as a

center, with a radius $O\,B$ equal to 2,864.93 feet, we describe an arc $B\,D$ 100 feet in length, the radii $O\,B$ and $O\,D$ will

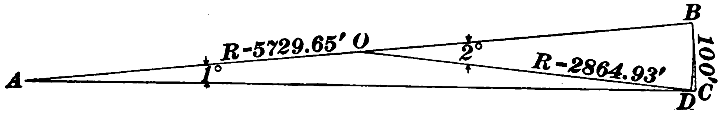


FIG. 281.

form an angle of 2° at the center O, and the curve $B\,D$ is called a 2° curve. A curve whose radius is nearly one-third $A\,B$, or 1,910.08 feet, is a 3° curve, etc.

The **degree of a curve** is determined by the central angle, which is subtended by a chord of 100 feet. Thus, if $B\,O\,G$ (Fig. 282) is 10° and $B\,G$ is 100 feet, $B\,G\,H\,K\,C$ is a 10° curve.

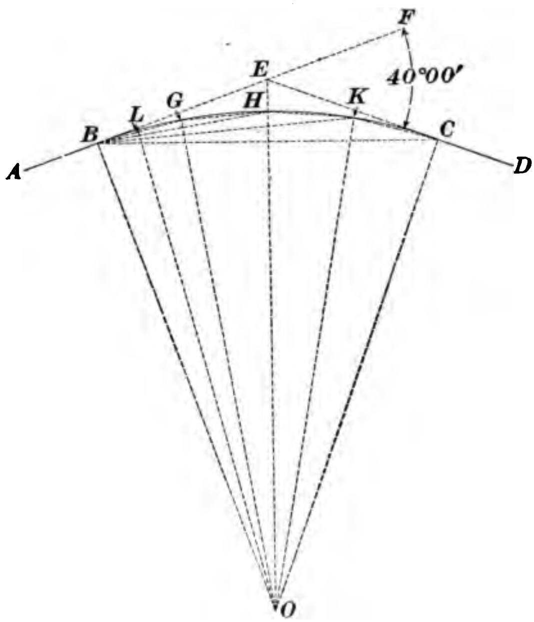


FIG. 282.

The **deflection angle** of a curve is the angle formed at any point of the curve between a tangent and a chord of 100 feet. The deflection angle is, therefore, **half the degree**

of the curve. Thus, if the chord BG is 100 feet, the angle EBG is the deflection angle of the curve $BGHKC$, and is half the angle BOG.

EXAMPLE.—Given the deflection angle $EBG = D$ (Fig. 282), to find the radius $BO = R$.

SOLUTION.—Draw OL perpendicular to BG. In the right-angled triangle BOL, we have $\sin BOL = \frac{BL}{BO}$; but $BOL = EBG = D$, since OL being perpendicular to the chord BG it bisects the arc BLG. But the angle $D = \frac{1}{2} BOG$; hence, angle $BOL = D$. $BL =$ 50 feet and the radius $BO = R$. Substituting these values in the given equation, we have $\sin D = \frac{50}{R}$; whence, $R \sin D = 50$, and we have the formula

$$R = \frac{50}{\sin D}. \qquad \textbf{(89.)}$$

For curves of from 1° to 10°, the radius may be found by dividing 5,730 ft. (the radius of a 1° curve) by the degree of the curve. The results obtained are sufficiently accurate for all practical purposes. For sharp curves, i. e., for those exceeding 10°, the above formula, viz., $R = \frac{50}{\sin D}$ should be used, especially if the radii are to be used, as a basis for further calculation.

For example, the radius of a 4° curve is found by both methods as follows: By first method, $R = 5,730 \text{ ft.} \div 4 = 1,432.5$ ft. By second method, we find the deflection angle D of a 4° curve is 2°. Applying the formula, $R = \frac{50}{\sin D}$, we have $R = \frac{50}{.0349} = 1,432.67$ ft.

In this case the error is only .17 foot, and may be ignored in practical work. For a 30° curve we have by first method, $R = \frac{5,730}{30} = 191$ ft. By second method, we have $R = \frac{50}{\sin 15^\circ} = \frac{50}{.25882} = 193.18$ ft. In this case the error is 2.18 ft., and the error increases as the degree of curve increases.

The *radii* given in the table of Radii and Deflections are calculated by the formula $R = \frac{50}{\sin D}$.

1250. Sub-Chords for Curves of Short Radii.—On curves of short radii, i. e., curves of 20° and upwards, center stakes are driven at intervals of 25 feet. In Art. **1248,** we stated that the standard chord and arc are assumed to be of the same length. This is practically true

for curves of large radii, but for curves above 20° the excess of length of arc over the chord constantly increases. If, now, in Fig. 282, the chord $B\ C$ is 100 feet in length, the arc $B\ G\ H\ K\ C$ must be *greater* than 100 feet; and if the arcs $B\ G$, $G\ H$, $H\ K$, and $K\ C$ are equal, i. e., each equal to one-quarter the arc $B\ H\ C$, then the equal chords $B\ G$, $G\ H$, $H\ K$, and $K\ C$ subtending these equal arcs must each be *greater* than one-quarter of $B\ C$, which we assumed to be 100 feet. These greater chords must, therefore, be *greater than 25* feet. Suppose the curve $B\ H\ C$ to be a 20° curve, and the chord $B\ C$, 100 feet; then the central angle $B\ O\ C$ is 20°. As the arc $B\ G$ is one-quarter of the arc $B\ H\ C$, the central angle $B\ O\ G$ is $\frac{20°}{4} = 5°$. The line $O\ L$, drawn to the middle point of the chord $B\ G$, is perpendicular to $B\ G$ and bisects the angle $B\ O\ G$. The deflection angle $E\ B\ G = B\ O\ L = G\ O\ L$. Let C designate the chord $B\ G$, R, the radius $O\ B$ and D, the deflection angle, $E\ B\ G = B\ O\ L$. In the right-angled triangle $B\ O\ L$, we have $\sin B\ O\ L = \frac{B\ L}{B\ O}$. Substituting the above given values, we have $\sin D = \frac{\frac{1}{2}C}{R}$, whence $\frac{1}{2}\ C = R \sin D$, and we have

$$C = 2\ R \sin D. \qquad \textbf{(90.)}$$

The central angle for the chord $B\ G$ is 5°. The deflection angle D is, therefore, $\frac{5}{2}° = 2°\ 30'$. Sin $2°\ 30' = .04362$. Since the deflection angle $E\ B\ C = 10°$ for this case, $R = 50 \div \sin 10° = 287.94$ ft. Hence, chord $C = 2 \times 287.94 \times .04362 = 25.12$ ft.

Accordingly, in measuring the short chords, 25.12 feet should be used instead of 25 feet.

1251. Tangent Distances.—When an intersection of tangents has been made and the intersection angle measured, the next question is the degree of curve which is to unite them, which being decided, the next step in order is the location of the points on the tangents where the curve

begins and ends. These two points are equally distant from the point of intersection of the tangents, which is called the P. I. The point where the curve begins is called the **point of curve**, or the P.C.; the point where the curve terminates is called the **point of tangent,** or the P. T. The distance of the P. C. and P. T. from the P. I. is called the **tangent distance.**

In Fig. 282, let $A\ B$ and $C\ D$ be tangents intersecting at the point E and forming an angle $C\ E\ F = 40°\ 00'$ with each other. It is decided to unite these tangents by a 10° curve whose radius is 573.7 feet. Call the angle of intersection I, the radius $B\ O$, R, and the tangent distance $B\ E$, T. From Art. **1247,** proposition 6, we have $B\ O\ C = C\ E\ F$; hence, the angle $B\ O\ E = \frac{1}{2}\ C\ E\ F$. From the right triangle $E\ B\ O$ we have $\tan B\ O\ E = \frac{B\ E}{B\ O}$.

Substituting the above equivalents we have $\tan \frac{1}{2} I = \frac{T}{R}$, whence

$$T = R \tan \tfrac{1}{2} I. \qquad \textbf{(91.)}$$

In our example $R = 573.7$ ft.; $\frac{1}{2} I = 20°$; $\tan 20° = .36397$. $573.7 \times .36397 = 208.81$ ft. Measure back from the point E on both tangents the distance 208.81 ft. to the points B and C. Drive plugs flush with the ground at both points and set accurate center points, marked by tacks, in both. Directly opposite each of these plugs drive a stake called a **guard stake,** because it guards or rather indicates where the plug is. The stake at B, if the numbering of the stations runs from B towards C, will be marked P. C., and the stake at C marked P. T.

1252. To Lay Out a Curve With a Transit.—Having set the tangent points B and C, Fig. 282, set up the transit at B, the P. C. Set the vernier at zero and sight to E, the intersection point. Suppose B to be an even or "full station," say 18, and that it has been decided to set stakes at each hundred feet. Let the central angle $B\ O\ G$, measured by the 100-feet chord $B\ G$, be 10°; then, the deflection angle $E\ B\ G$, whose vertex B is in the circum-

ference and subtended by the same chord $B\,G$, will be $\frac{1}{2}$ $B\,O\,G$ or 5°. Turn an angle of 5° from B, which in this case will be to the right; measure a full chain, 100 feet, from B and line in the flag at G; drive a stake at G, which will be marked 19. Turn off an additional 5° making 10° from zero, and at the end of another chain, at H, set a stake marked 20. Continue turning deflections of 5° until 20° or one-half of the intersection angle is reached. This last deflection, if the work has been correctly done, will bring the head chainman to the point of tangent C. It is but rarely that the P. C. comes at a full station. When the P. C. comes between full stations it is called a **sub-station,** and the chord between it and the next full station is called a **sub-chord.** Had the P. C. of the curve come at the sub-station, say 17 + 32, the deflection for the sub-chord of 100 – 32 or 68 feet, the distance to the next station, is found as follows: The deflection for a full station, i. e., 100 feet, is $5° = 300'$, and the deflection for 1 foot is $\frac{300'}{100} = 3'$, and for 68 feet the deflection will be $68 \times 3 = 204' = 3°\,24'$, which is turned off from zero and a stake set on line, 68 feet from the transit, at Station 18. The length of a curve uniting two given tangents whose intersection angle is determined, is found as follows:

Suppose $I = 32°\,40'$, and that the tangents are to be united by a 6° curve; 32° 40′ reduced to the decimal form is 32.666°; as each central angle of 6° will subtend a 100-foot chord, or one chain, there will be as many such chords or chains as 6 is contained times in 32.666, which is 5.444, that is, there will be 5.444 chains in the curve, or 544.4 feet, which is the required length of the curve. The P. C. and P. T. having been set and the station of the P. C. determined by actual measurement, say 58 + 71, the station of the P. T. is found by adding to 58 + 71, the station of the P. C., the calculated length of the curve, 544.4 feet. $58 + 71 + 544.4 = 64 + 15.4$, the station of the P. T.

Another method of calculation is the following: The sum of all the deflection angles is equal to one-half the intersection

angle. The intersection angle being 32° 40′, one-half equals 16° 20′, which, reduced to minutes, equals 980′. The deflection for 100 feet is $\frac{6}{2}^{\circ} = 3° = 180'$, and the deflection for 1 foot is $\frac{180'}{100} = 1.8'$; then, 980′, the total deflection, divided by 1.8′, gives 544.4 feet, the required length of the curve.

EXAMPLES FOR PRACTICE.

In the following examples, let I = angle of intersection, T = tangent, and L = length of curve.

1. $I = 16° 13'$, degree of curve = 3°, required, T and L.

Ans. $\begin{cases} T = 272.18 \text{ ft.} \\ L = 540.55 \text{ ft.} \end{cases}$

2. $I = 59° 20'$, degree of curve = 8° 30′, required, T and L.

Ans. $\begin{cases} T = 384.32 \text{ ft.} \\ L = 698.04 \text{ ft.} \end{cases}$

3. $I = 21° 35'$, degree of curve = 4° 15′, required, T and L.

Ans. $\begin{cases} T = 257.03 \text{ ft.} \\ L = 507.84 \text{ ft.} \end{cases}$

4. The degree of a curve is 5° 30′; what is the deflection angle for a chord of 16.2 feet? Ans. 26.7′.

5. The degree of a curve is 7° 15′; what is the deflection angle for a chord of 38.4 feet? Ans. 1° 23½′.

1253. Obstructions in the Line of Curve.—Frequently it happens that the entire curve can not be run in from the P. C. on account of obstructions. This is especially the case in either hilly or wooded country, and the transit has to "move up" to an intermediate point. For example, in Fig. 282, we will suppose that Station H, 200 feet from B, is the last point which can be set from the P. C. at B. A plug is driven at H flush with the ground and carefully centered, and a tack driven at the point. The deflection angle $E B H$ is 10° to the right. The transit is set up at H, an angle of 10° to the left is laid off from zero, and the vernier clamped. The instrument is then sighted to a flag at B, the spindle clamped, and a close sight to the flag taken, the lower tangent screw being used to adjust the sight. The vernier clamp is then loosened and the vernier

set at zero. The line of sight will then be on a tangent to the curve at H, and the deflection angles to K and C can be laid off as before and the stations K and C located.

1254. Tangent and Chord Deflections.—Let $A\ B$ in Fig. 283 be a tangent, and $B\ C\ E\ H$ a curve commencing at B. Produce the tangent $A\ B$ to the point D. The line $C\ D$ is a **tangent deflection,** and is the perpendicular distance from the tangent to the curve. If the chord $B\ C$ be produced to the point G, making $C\ G = B\ C = C\ E$, the distance $G\ E$ is a **chord deflection** and is double the tangent deflection $D\ C$.

1255. Given the radius $B\ O = R$, Fig. 283, to find the chord deflection $E\ G$ and the tangent deflection $C\ D = F\ E$.

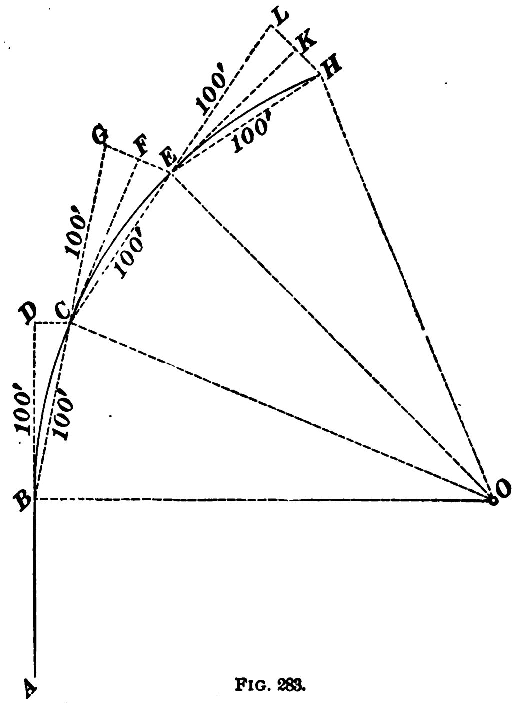


FIG. 283.

The triangles $O\ C\ E$ and $C\ E\ G$ are similar, since both are isosceles, and the angle $G\ C\ E$ = angle $C\ O\ E$. Hence,

we have $O\,C : C\,E :: C\,E : E\,G$. Denoting the chord $C\,E$ by c and the chord deflection $E\,G$ by d, we have, from the above proportion, $R : c :: c : d$. Therefore,

$$d = \frac{c^2}{R}. \qquad \textbf{(92.)}$$

To find the tangent deflection, draw $C\,F$ to the middle point of $E\,G$. By Art. **1254,** $F\,E = D\,C =$ the tangent deflection. Hence, tangent deflection = one-half the chord deflection, from which

$$\text{tangent deflection} = \frac{c^2}{2\,R}. \qquad \textbf{(93.)}$$

1256. Practical Method of Determining Tangent and Chord Deflections.—Let it be remembered for a basis of calculation that the chord deflection for a one-degree curve, the chord being 100 feet in length, is 1.745 feet; for a 2° curve, double the deflection for a 1° curve, or 3.49 feet, and so on. The tangent deflection being one-half the chord deflection, for a 1° curve it will be .873 foot, for a 2° curve it will be 1.745 feet, etc.

Distances measured either on chords or tangents are expressed in decimal parts of a station, which is 100 feet, and

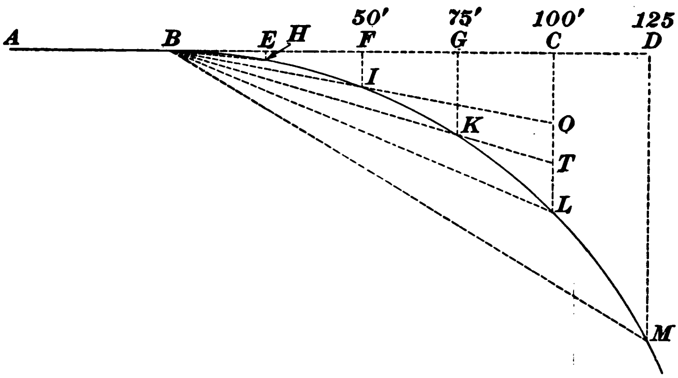


FIG. 284.

is assumed as 1. Thus, the tangent deflection for 75 feet will be expressed as the tangent deflection for .75 of a station. This expression is, however, confined entirely to

the calculation, and is *spoken of* as the deflection for 75 feet.

The tangent to a curve is fixed in direction, being perpendicular to the radius at the point of tangency. Consequently, in a curve of given radius, the value of the tangent deflection depends wholly upon the length of the chord. Formula **93** shows that the tangent deflection is proportional to the square of the chord. Hence, knowing the tangent deflection for a chord of 100 feet, the tangent deflection for a chord of any other length can be found by the

Rule.—*Multiply the tangent deflection for a chord of 100 feet by the square of the given chord expressed as a decimal.*

Let $B\ K\ M$, Fig. 284, represent a 2° curve. For the chord $B\ L$ of 100 feet, the tangent deflection is 1.745 feet. Hence, for the chords $B\ I = 50$ ft., $B\ K = 75$ ft., and $B\ M = 125$ ft., the tangent deflections are, respectively, $.50^2 \times 1.745 = .436$ ft., $.75^2 \times 1.745 = .982$ ft., and $1.25^2 \times 1.745 = 2.727$ ft.

It is here assumed that the chords and corresponding tangents are of equal lengths. This is not strictly true, but is near enough when the degree of curve is small.

The above principle does not apply to chord deflections, however. The point G, Fig. 283, is in the prolongation of the chord $B\ C$, and the value of the chord deflection $G\ E$ is affected by the direction, and consequently, by the length, of $B\ C$. In the triangle $G\ C\ E$, the angle $G\ C\ F = \frac{1}{2}\ B\ O\ C$ and $F\ C\ E = \frac{1}{2}\ C\ O\ E$. Consequently, the triangle $G\ C\ E$ can be isosceles and similar to $C\ O\ E$ only when the angle $C\ O\ E = B\ O\ C$, that is, when $B\ C = C\ E$. Hence, formula **92** applies only *when the two chords preceding the station considered are of equal length.* When these chords are of different lengths, the chord deflection will be given closely by formula **92** if $\frac{1}{2}\ c\ (c + c')$ is substituted for c^2, where c' is the length of the second chord preceding the station. Or, if the *tangent* deflection f has been computed, the chord deflection d_o will be given closely by the formula

$$d_o = f\left(1 + \frac{c'}{c}\right). \qquad (\mathbf{92}a.)$$

1257. Laying Out Curves Without a Transit.—During construction, the engineer is often called upon to restore center stakes on a curve when the transit is not at hand. This can be accomplished reasonably well with a tape, as described in the following example.

In Fig. 285, $A\ B$ is a tangent and B, at Sta. $8+25$, is the *P. C.* of a 4° curve; a stake is required at each full station. The stakes at A and B are restored, determining the *P. C.* and the direction of the tangent. For a 4° curve the regular chord deflection for 100 feet is $4 \times 1.745 = 6.98$ ft., and the tangent deflection is 3.49 ft.

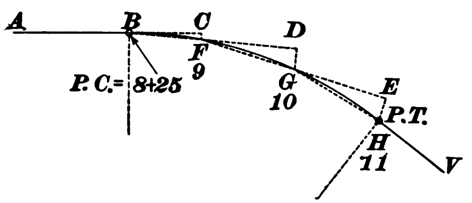


FIG. 285.

The distance from the *P. C.* to the next station C is 75 ft.; hence, the tangent deflection $C\ F = .75^2 \times 3.49 = 1.96$ ft. (Art. **1256.**) The point F is found by first measuring 75 feet from B, thus locating the point C, in the line with $A\ B$, then from C measuring $C\ F = 1.96$ feet, at right angles to $B\ C$; the point F thus determined will be Station 9. Next the chord $B\ F$ is prolonged 100 feet to D; as $B\ F$ is only 75 feet, formula **92*a*** gives for $D\ G$ the value $3.49 \times (1 + \frac{75}{100}) =$ 6.11 feet. This distance is measured at right angles to $C\ D$; the point G thus determined will be Station 10. The position of Station 11, the *P. T.*, is determined in the same manner, except that, as the chords $F\ G$ and $G\ H$ are each 100 feet long, the regular chord deflection of 6.98 feet is used for $E\ H$. A stake is driven at each station thus located. Although a chord deflection is not at right angles to the chord theoretically, yet the deflection is so small, as compared with the length of the chord, that for curves of ordinary degree it is usually measured at right angles.

EXAMPLES FOR PRACTICE.

1. In a 5° curve, what are the tangent and chord deflections for a chord of 67 ft. following one of 100 ft.? Ans. $\begin{cases} f = 1.958 \text{ ft.} \\ d = 4.880 \text{ ft.} \end{cases}$

2. In a 7° 30′ curve, what are the tangent and chord deflections for a chord of 23.5 ft. following one of 100 ft.? Ans. $\begin{cases} f = .361 \text{ ft.} \\ d = 1.897 \text{ ft.} \end{cases}$

3. In a 6° 15′ curve, what are the tangent and chord deflections for a chord of 100 ft. following one of 84 ft.? Ans. $\begin{cases} f = 5.451 \text{ ft.} \\ d = 10.030 \text{ ft.} \end{cases}$

1258. To Determine Degree of Curve by Measuring a Middle Ordinate.—In track work, it is often necessary to know the degree of a curve when no transit is available for measuring it. The degree can be found by measuring the middle ordinate of any convenient chord, and multiplying its length by 8, which will give the chord deflection for that curve.

Let $A\ B$, in Fig. 286, be a 50-foot chord, measured on the track, and let the middle ordinate $a\ b$ be .44 ft. $.44 \times 8 = 3.52$ = chord deflection for 50′, which, expressed in decimal part of a full station, is .5; $.5^2 = .25$. The chord deflection for 100 feet multiplied by .25 = the chord deflection for 50 feet, which we know by calculation to be 3.52 feet. Hence, $3.52 \div .25 = 14.08$ ft., the chord deflection for 100 feet, which, divided by 1.745, the chord deflection for a 1° curve, gives a quotient of 8.07, nearly. The inference is that the curve is 8°.

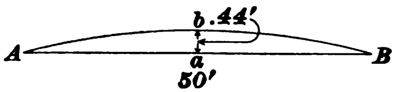


FIG. 286.

EXAMPLES FOR PRACTICE.

1. Length of chord is 50 ft., middle ordinate .35 ft.; required, degree of curve. Ans. 6° 25.08′.

(The original curve probably 6° 30′.)

2. Length of chord 40 ft., middle ordinate .21 ft.; required, degree of curve. Ans. 6° 1.02′.

(The original curve probably 6°.)

3. Length of chord 25 ft., middle ordinate .22 ft.; required, degree of curve. Ans. 16° 8.28′.

(The original curve probably 16°.)

1259. Field Books.—To facilitate the field work of the engineer, **field books** have been published. They are portable, being carried in the pocket, and contain, in condensed form, general directions for the conduct of field work, together with all the necessary data in the form of tables, for prosecuting such work with accuracy and dispatch.

One of the first published in America is the work of John B. Henck, to whom most American engineers are under obligation.

1260. Note Books.—Various styles of note books are published, the pages being ruled to suit the particular kind of work being done. They are of three classes, viz., transit, level, and topography books. The latter are ruled in squares, which may be given any desired scale and greatly facilitate the accurate platting of topography in the field.

1261. How to Keep Transit Notes.—

A good form for location notes is the following:

Station.	Deflection.	Tot. Angle.	Mag. Bearing.	Ded. Bearing.	Remarks.	June 20. 189[illegible]
9						
8						
7						
6+95	4°54′ P.T.	15°00′	N. 35°30′ E.	N. 35°15′ E.		
6+50	4°00′					
6	3°00′					70°00′
5+50	2°00′				5+80	Centerline of Highway
5	1°00′				5+60	
4+50	2°36′	5°12′				
4	1°36′				Int. Angle = 15°00′	4° Curve R^t
3+50	0°36′				T = 188.61 ft.	Def. Angle for 60 ft. 1°00′
3+20	P.C. 4° R^t				P.C. = 3+20	Def. Angle for 1 ft. = 1.2′
3					Length of Curve = 375 ft.	
2					P.T. = 6+95	
1						
0			N. 20°15′ E.	N. 20°15′ E.		

In the first column the station numbers are recorded. In the second column are recorded the deflections with the abbreviations P. C. and P. T., together with the degree of curve and the abbreviation R^t or L^t, according as the line curves to the right or left. At each transit point on the

curve, the total or central angle from the P. C. to that point is calculated and recorded in the third column. This total angle is double the deflection angle between the P. C. and the transit point. In the above notes, there is but one intermediate transit point between the P. C. and the P. T. The deflection from the P. C. at Sta. 3 + 20 to the intermediate transit point at Sta. 4 + 50 is 2° 36′. The total angle is double this deflection, or 5° 12′, which is recorded on the same line in the third column. The record of total angles at once indicates the stations at which transit points are placed. The total angle at the P. T. will be the same as the angle of intersection, if the work is correct. When the curve is finished, the transit is set up at the P. T., and the bearing of the forward tangent taken, which affords an additional check upon the previous calculations. The magnetic bearing is recorded in the fourth column, and the deduced or calculated bearing is recorded in the fifth column.

1262. Preservation of Notes and Records.—Notes should *never be erased.* If, on account of error or change of plan, they should cease to be of any value, they are crossed out, i. e., two diagonals are drawn across the page. All notes of permanent location should be copied each day into a separate book for office reference, to prevent confusion, and for record in case the original notes should be lost.

LEVELING.

1263. A Level Surface.—A level surface is one parallel to the surface of standing water. A water surface, though not theoretically level, owing to the curvature of the earth's surface, is assumed to be level and perpendicular to a vertical line, or the line of gravity.

The height of a point is its distance above a given level surface, measured on a vertical line, and is called its **elevation.** The process by which the elevation of a point is determined is called **leveling.**

1264. The Three Processes of Determining Elevations.

They are : 1st. By direct leveling.
2d. By indirect leveling ; and
3d. By barometric leveling.

1265. Direct Leveling.—In the process of direct leveling, a level line either actual or visual is prolonged so as to pass directly over or under the given point whose elevation is required. The elevation of any other point being determined in the same way, the difference in the elevations of the two points is found by subtracting the elevation of the lower from the elevation of the higher.

1266. Indirect Leveling.—In the process of indirect leveling, elevations are determined by means of lines and angles.

1267. Barometric Leveling.—In barometric leveling the elevation of a point is determined by the weight of the atmosphere at that point as registered by a barometer. The second and third processes will be explained later.

DIRECT LEVELING.

1268. General Principles.—Direct leveling depends upon three principles, two of which have already been stated, viz.: First, that the surface of a liquid in repose is level; second, that a vertical line is perpendicular to that surface, and, third, that a bubble of air confined in a vessel otherwise filled with liquid will rise to the highest point of that liquid. A common application of the third principle is seen in the spirit level used by carpenters and the level board used by masons.

1269. The "Y" Level.—There are a great variety of instruments for determining elevations. The one in most general use is the "**Y**" level, shown in Fig. 287.

This instrument consists of an **erecting telescope** *A B*, i. e., one which shows the image of the object to which the telescope is directed in its erect or natural position, resting in **Y**-shaped supports *C* and *D*, from which it takes its name.

The line of sight, or collimation, is identical to that in the transit explained in Art. **1225**, and is parallel to the level $E F$. The tube containing the eyepiece G has an exterior ring H, which is milled to assist the hand in turning the tube. This movement adjusts the eyepiece to the cross-hairs. The object glass at B is moved in or out by the milled headed screw K; L and M are parallel plates; the bar $O P$ supports the **Y**'s and revolves on a spindle which is

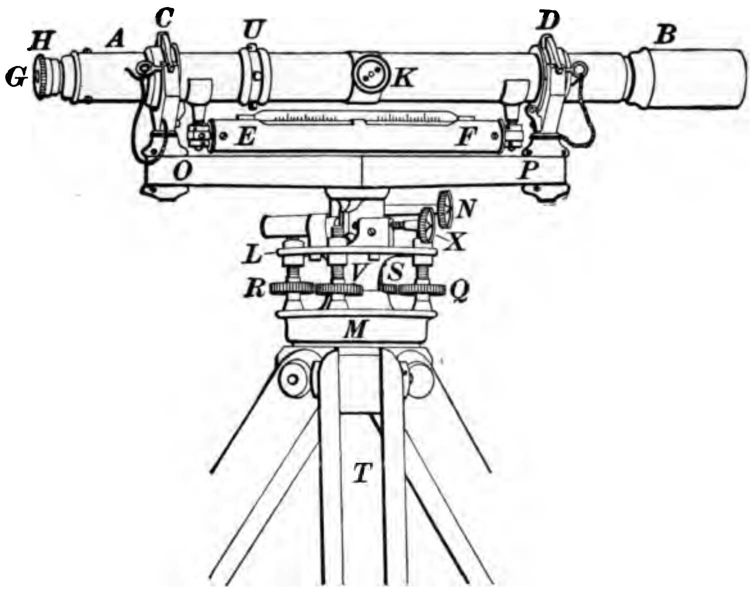


FIG. 287.

clamped by the screw N. By means of the tangent screw X, the telescope can be slowly turned horizontally. The telescope is leveled by means of the leveling screws V, Q, R, and S. The level is supported by the tripod T. The cross-hairs are of either platinum wire or spider threads, and are fastened to a ring which is held in place by capstan screws shown at U, and their movements are regulated in the same way as the movements of the cross-hairs of the transit explained in Art. **1225.**

1270. The Bubble Tube.—The bubble tube is of glass bent upwards and so nearly filled with alcohol that only a bubble of air remains, which is always at the highest point in the tube. This tube is protected by a brass case, which is fastened to the underside of the telescope, and provided with the means for adjustment. The one end may be raised or lowered and the other end moved horizontally. Through a slit in the upper side of the case, the bubble tube is seen. Directly over it is a scale graduated in both directions from zero, which is over the center of the tube.

The **Y's** *C* and *D* support the telescope, which is held in place by hinged clasps, or **clips,** as they are called, fastened by carefully turned pins, by means of which the telescope can be firmly held in any desired position. The **Y's** rest upon the bar *O P*, to which they are fastened by lock-nuts, the one above, the other below, the bar, for raising or lowering. The bar revolves upon a finely turned steel spindle, resting in a socket of bell metal. The parallel plates *L* and *M* are united by a ball-and-socket joint, and held in place by the leveling screws *V*, *Q*, *R*, and *S*.

1271. Adjustments.—The first thing to do in preparation for actual leveling is to make the adjustments of the instrument.

There are three adjustments, as follows:

1. To make the line of collimation parallel to the bottoms of the collars, or rings, on which the telescope rests.

2. To make the plane of the level parallel to the line of collimation, or to the bottom of the collars.

3. To cause the bubble to remain in the center of the tube while the telescope is being revolved horizontally.

1272. First Adjustment.—To make the line of collimation parallel with the bottoms of the collars.

Plant the tripod firmly; choose some distant and clearly defined point, the more distant the better so long as the sight is distinct. Remove the pins from the clips and clamp the spindle, bringing the intersection of the cross-hairs to

exactly bear on the point by means of the tangent screw. Revolve or turn the telescope on its supports through one-half a revolution, i. e., until it is bottom side up. If the intersection of the cross-hairs is still on the point of sight, it proves that the line of collimation is parallel to the bottoms of the collars. If, however, the line of sight is no longer on the point, move the cross-hairs by means of the capstan headed screws over one-half the space which measures the apparent error, being careful to move them in the opposite direction to that in which it would appear they should be moved. The apparent error is double the real error, and is explained in Fig. 288.

Let the instrument stand at *A* and sight to the point *B*, and suppose that when the telescope has been revolved half way around, the point *B* appears to be at *C*, then will the

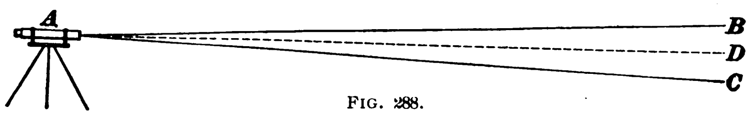


FIG. 288.

distance *B C* be double the real error, and the true line of sight will be at *D*, half way between *B* and *C*. Sometimes both cross-hairs are out of adjustment and they must be moved alternately until the intersection of the cross-hairs, i. e., the line of collimation, will pass through the same point throughout a complete revolution of the telescope.

1273. Second Adjustment.—The second adjustment is to make the plane of the level parallel to the line of collimation, or to the bottoms of the collars, and is made as follows:

Remove the pins and open the clips; place the telescope over a pair of leveling screws and clamp the spindle. Bring the bubble to the middle of the tube by means of the leveling screws, and revolve the telescope through an eighth of a revolution. The bubble tube will stand out at an angle with the Y's. If the bubble runs it shows that a vertical plane passed through the longitudinal axis of the bubble tube is not parallel to a vertical plane passed through the line of

collimation. To correct the error, bring the bubble nearly back by means of the check nuts which regulate the lateral movement of the tube, and repeat the operation until the bubble ceases to run while the partial revolution is made. To complete the bubble adjustment, level the telescope and take it out of the Y's and turn it "end for end." If the bubble remains in the center of the tube, the second adjustment is complete. If it runs to one end, bring it half way back by means of the check nuts provided for raising or lowering one end, and the rest of the way, i. e., to the middle of the tube, by means of the leveling screws. Repeat the operation, as the adjustment can rarely be made with one trial.

1274. Third Adjustment, sometimes called the "**Bar Adjustment.**"—This is to cause the bubble to remain in the center of the tube while the telescope is being revolved horizontally.

Level the instrument, using both sets of leveling screws. Having centered the bubble carefully with one pair of leveling screws, turn the telescope until it stands directly over the other pair of leveling screws. If the bubble runs, bring it half way back by means of the locknuts at the end of the level bar and complete the leveling with the leveling screws. Repeat the operation, as two or three trials will probably be necessary to complete the adjustment, so that the bubble will remain in the center of the tube throughout an entire horizontal revolution of the telescope.

The adjustments of the level should be tested every day when in constant use, as any defect in them will detract from the value of the work done, and a serious defect will necessitate a repetition of the work.

The cross-hairs are placed at right angles to each other, one of which should be vertical and indicate to the leveler whether the leveling rod is being held plumb. If the vertical cross-hair is "out of plumb," adjust it by loosening the capstan screws which hold the ring, to which the cross-hairs are fastened. Suspend a plumb-bob at a suitable distance

from the level, and having sighted to it, tap the capstan screws sufficiently hard to cause the cross-hairs to move. In this way the vertical hair can be made to coincide with the plumb line, which is a true vertical.

1275. Sensibility.—The sensibility of the level depends directly upon the radius of the curve of the bubble tube.

The graduated scale placed directly over the bubble tube measures the movement of the bubble. The sensibility of the level may be determined as follows: Having leveled the instrument, take a reading on the rod held say 200 feet from the instrument. Suppose this reading to be 5.61 feet; with the leveling screws cause the bubble to move over one division of the scale. Suppose the rod then reads 5.63 feet. Denote the radius of the bubble by x, Fig. 289, the distance

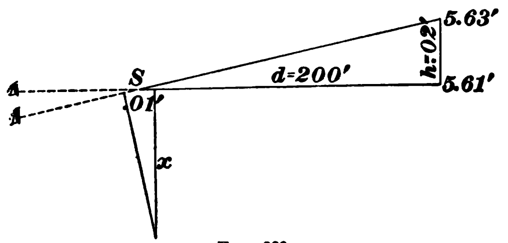


FIG. 289.

of the rod from the instrument by d, the difference of rod readings by h, and the movement of the bubble by S. From the approximately similar triangles we have $h : S :: d : x$, or $.02 : .01 :: 200 : x$, whence $x = \frac{2.00}{.02} = 100$ feet, the radius of the bubble tube.

1276. Use and Care of the Level.—The level should not be used in rainy weather if it can be avoided. Moisture obscures the lenses and is otherwise injurious to the instrument. When rain is unavoidable, wipe the lenses frequently with a soft linen handkerchief, and when returned to the office or camp, thoroughly wipe, finishing with a piece of dry chamois skin and place in a warm, dry place so that every particle of moisture may be removed. Never

carry the level with the spindle clamped. This rule is especially important when working in a wooded country where underbrush is dense. When *unclamped*, the level turns freely upon the spindle and yields readily to any pressure. A blow which would inflict no injury upon an *unclamped* instrument might seriously damage one while *clamped* and *rigid.*

1277. Power and Definition.—The power of a telescope is measured by the apparent nearness to which the image of the object is brought to the eye of the observer.

The definition of a telescope is measured by the degree of clearness of the outline of the image.

1278. Target Rods.—Target rods are divided into two classes, viz., those which are self-reading, or speaking rods, and those which are not self-reading. Railroad work is done chiefly with a self-reading rod. That in most general use is called the Philadelphia rod, and is shown in Fig. 290. It is in two sections held together with brass clamps A and B, one section sliding over the other. When closed, the rod measures 7 feet, sliding to 12 feet. It is graduated to feet, tenths, and hundredths. The feet are marked in large red figures, half above and half below the marks of division; tenths of feet are marked in black figures from 1 to 9, the lines of division reaching half way across the face of the rod; hundredths are marked by lines $\frac{1}{100}$ of a foot in width, alternating white and black, and extending about one-third the way across the face of the rod. The target is either circular or elliptical and divided into quarters, alternating red and white. The division lines are so arranged that when the rod is held in a vertical position one of them will be horizontal and the other vertical. The target C is fastened to a collar which slides up and down the rod, and is

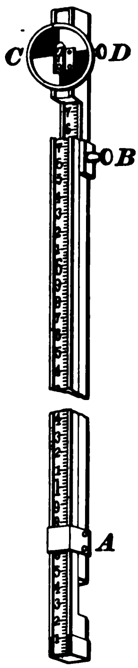


Fig. 290.

fitted with a screw D, which clamps it at any desired point. An opening more than one-tenth of a foot in length is cut in the face of the target. A vernier is fastened to the target whose zero point exactly coincides with the line which divides the target horizontally. It lies within the opening, on the face of the rod, and reads to thousandths of a foot. To prevent wear, the foot of the rod is shod with brass. Rod readings under 7 feet are usually taken with the two sections closed, and the target moved up or down until the horizontal line on the target coincides with the horizontal cross-hair of the telescope. When readings of more than 7 feet are taken, the clamp at B is loosened and the sliding section moved upwards until the horizontal line of the target and the horizontal cross-hair of the telescope coincide. The rod is then clamped, and is called a **long** or **high rod,** and can be read to thousandths with the vernier attached to the collar at B. In setting the target, the leveler should read the rod as closely as he can with the level, calling the reading to the rodman, who sets the target at the given reading and holds the rod up for a **check reading.** Four times out of five the leveler's reading will be the correct one, even to thousandths. More mistakes are made in reading the number of feet than the number of tenths. The leveler by first calling the reading to the rodman will be certain to prevent such an error, as it would at once be detected in the check reading. An experienced rodman can hold a rod practically plumb, and for all ordinary work his care is considered sufficient. For work requiring the greatest possible accuracy, such as bridge foundations, a hand level, which fits closely to the angle of the rod and carries two small spirit levels, is used to accurately plumb it. In using a rod which is not self-reading, all readings are taken with the target.

1279. Examples in Direct Leveling.—The principles of direct leveling are illustrated in Fig. 291.

Let A be the starting point, which has a known elevation of 20 feet. The instrument is set at B, leveled up, and sighted to a rod held at A. The target being set, the reading,

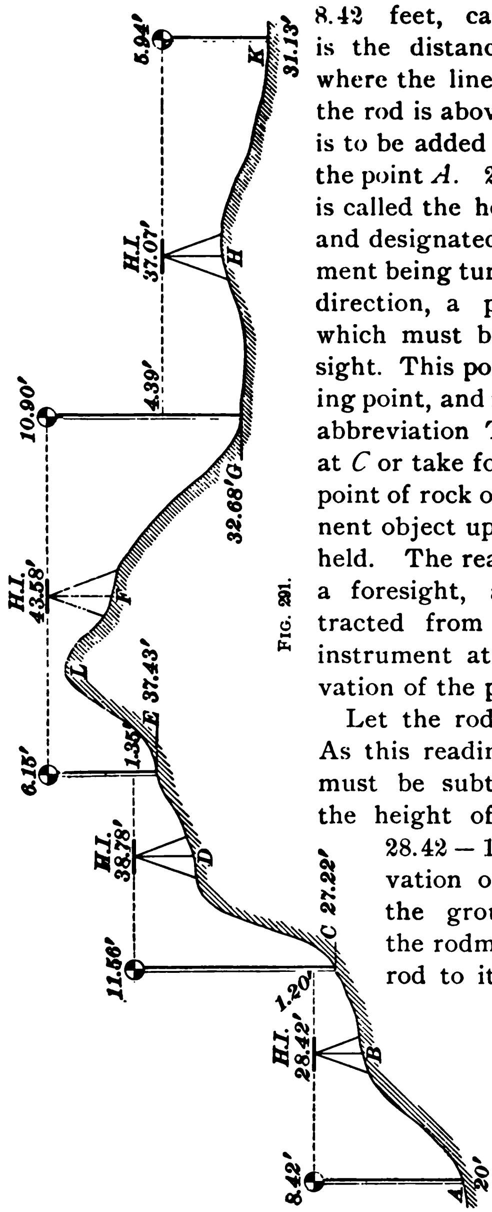


FIG. 291.

8.42 feet, called a backsight, is the distance which the point where the line of collimation cuts the rod is above the point A, and is to be added to the elevation of the point A. $20.00 + 8.42 = 28.42$ is called the height of instrument and designated H. I. The instrument being turned in the opposite direction, a point C is chosen, which must be below the line of sight. This point is called a turning point, and is designated by the abbreviation T. P. Drive a peg at C or take for a turning point a point of rock or some other permanent object upon which the rod is held. The reading at this point is a foresight, and is to be subtracted from the height of the instrument at B to find the elevation of the point at C.

Let the rod reading be 1.20 ft. As this reading is a foresight, it must be subtracted from 28.42, the height of instrument at B; $28.42 - 1.20 = 27.22'$, the elevation of the point C. As the ground rises abruptly, the rodman should slide the rod to its full length, being careful to keep it on the same point C. The leveler carries the instrument to D, which should be of such a height above C that when

leveled up the line of sight will cut the rod near the top. The backsight to C gives a reading of 11.56 ft., which, added to 27.22 ft., the elevation of C, gives 38.78 ft., the height of the instrument at D. The rodman then goes to E, a point where a foresight reading is 1.35, which, subtracted from 38.78, the H. I. at D, gives 37.43 feet, the elevation of E. The level is then set up at F, being careful that the line of sight shall clear the hill at L. The backsight 6.15 ft. added to 37.43 ft., the elevation of E, gives 43.58 ft., the H. I. at F. The rod held at G gives a foresight of 10.90 ft., which, subtracted from 43.58, the H. I. at F, gives 32.68, the elevation at G. Again moving the level to H, the backsight to G of 4.39 ft. added to 32.68, the elevation of G, gives 37.07 ft., the H. I. at H. Holding the rod at K a foresight of 5.94 subtracted from 37.07 gives 31.13, the elevation of the point K. The elevation of the starting point A is 20.00 ft.; the elevation of the point K is found by direct leveling to be 31.13 ft., and the difference in the elevations of A and K is $31.13 - 20.00 = 11.13$ ft.; that is, the point K is 11.13 feet higher than the point A.

1280. A Datum Line.—A **datum line** is the base line to which the elevation of every point of a series is referred. Thus, in Fig. 291, the datum line or plane is 20 feet lower than the point A, and the elevations of the points $A, B, C, D \ldots K$ are their elevations above this datum line. Such a series of elevations is called a line of levels.

1281. Turning Points.—Turning points, mentioned in Art. **1279,** are the points where backsights and foresights are taken. The backsights are plus (+) readings, and are to be added; the foresights are minus (−) readings, and are to be subtracted. The rodman should make a peg of well-seasoned oak, or other hard wood, about 9 inches in length, 1 inch in diameter, sharpened at one end and rounded at the other end, which is the turning point. For driving the peg he should carry in a leather scabbard a light hatchet. A point for a foresight having been determined, the rodman drives the peg firmly in the ground and

holds the rod upon it. After the instrument is moved, set up, and a backsight taken, the peg is pulled up and carried in the pocket until another turning point is called for. Turning points should be taken at about equal distances from the instrument in order to equalize any small errors in adjustment. In smooth country an ordinary level will permit of sights of from 300 to 500 feet. A good rodman is as necessary to accurate and rapid leveling as a good leveler. A man who is inattentive to the work in hand, or averse to rapid movement, is not fit for either place. In most localities, a line of levels of any considerable length will have enough rough places in it, i. e., places where considerable changes in elevation occur, to retard progress, however diligent the level party may be. Laziness or carelessness merit immediate discharge, and usually receive it.

1282. Bench Marks.—On railroad surveys, permanent points called **bench marks** should be established at intervals of from 1,000 to 2,000 feet, depending upon the nature of the country. Any permanent object, such as a stone door sill, a tree, or point of large rock, will serve for a bench mark. Where trees are available, they are always used, the point being cut on a projecting root. On preliminary lines they should be as near to the line as possible. A tree with a large exposed root is chosen, the bench mark is cut into the root in the form of a pyramid, a tack is driven into the apex and the rod held upon it. The tree is blazed smooth and the letters B. M., together with the elevation of the mark, written with red chalk. A bench mark of this kind is shown in Fig. 292, the point being at *A* and the elevation recorded at *B*.

FIG. 292.

1283. Check Levels.—Check levels or test levels are taken for the purpose of checking and proving the accuracy

of a line of levels before their adoption as a basis for construction. Usually intermediate points or stations are not taken, but only the turning points necessary to cover the line. Readings are taken at all the bench marks, and the correct elevations marked. The adjustments of the instrument should be frequently tested, and the rodman should carry a rod level to insure the plumbing of the rod.

1284. Water Checks.—When the line of survey follows the shore of a body of water having no current, such as a lake or pond, its surface can be used as a check, since its level for any ordinary space of time will remain unchanged. The sea, whose level is constant, is the base for all barometric leveling, and at all seaports for direct leveling.

1285. Rapid Work.—The rate of progress is limited by the transit party. If the country is open and rolling, where long sights are frequent and chaining easy, the level party will not keep up with the transit party. If the country is smooth and open, both parties can make about the same progress. If, however, the country is thickly covered with underbrush or heavy timber, the level party will have much idle time. A good day's work will vary, according to conditions, from three to eight miles.

The target should be set by signals given by the leveler. An upward movement of the hand is the signal for raising the target, and a downward movement the signal for lowering it; a circle described by the hand is the signal for clamping the target, and a wave with both hands indicates that the target is properly set.

All intermediate readings are read by the leveler, whose signal "All right" is a single outward wave of the hand, the rodman being careful to keep the rod at full length.

The rodman should always call out the rod reading, giving first the number of feet, or, if the reading is less than 1 foot, call the figure "naught," never "ought," then pausing a moment, call the decimal part of the reading. If the rod is being read to hundredths only, the number, 8.40, is read:

eight-four, naught; if 8.04, it is read: eight-naught, four. If the rod is to be read to thousandths, the number, 8.401, is read: eight-four, naught, one; if 8.410, it is read: eight-four, one, naught.

The distinctness of a call is in no way proportional to the amount of noise in it. A few days' practice will enable a rodman with moderate effort to call a reading so as to be distinctly heard at a distance of 500 feet. Should a high wind be blowing, the sights will be shorter, owing to the vibration of the instrument, and the rodman's work proportionally lessened. The rod reading should always be recorded before moving the instrument. The leveler may check the reading as he passes the rodman. In general, however, the leveler relies entirely upon the accuracy of the rodman's readings. If he can not be trusted, his place should at once be supplied by one who can be trusted.

In taking levels on preliminary railroad surveys, frequently the turning points, as well as intermediate stations, are read by the leveler without being checked by the target. The rodman has still plenty of occasion for the use of judgment, as the rate of progress depends largely upon the care shown in the selection of turning points.

1286. Sources of Error.—The principal sources of error are defects in adjustment, which are the fault of the leveler, and failure of the rodman to plumb the rod, and wrong target readings, which are the fault of the latter. Poor levelers and poor rodmen usually go in pairs. Haste or hurry are poor helps to progress. One can do rapid and accurate work without haste, but can not hurry and be either rapid or accurate.

The sun shining directly upon the object glass confuses the sight. To prevent this, most instruments are provided with a sun shade, which fits the end of the telescope, projecting over the object glass.

If the sun shade is lacking, the leveler can hold his hat so as to shade the object glass.

Wind is also a source of error, as it causes the instrument

to vibrate, thus preventing the accurate setting of the target. The leveler should wait for a lull in the wind, during which, if his rodman is alert, he can get a close shot. At a second lull, he can check the target and feel safe in moving ahead.

Individual errors, called "personal equation," are defects in vision peculiar to the individual, so that two persons may set a target for the same rod, each giving a different reading; but as this personal equation, or error, is constant for the same person, it does not materially affect the accuracy of work.

1287. Necessary Degree of Accuracy.—In preliminary railroad work an error of .10 of a foot per mile is allowable. Time spent in reducing such inaccuracies is wasted. That painful degree of accuracy termed "hair-splitting" is no recommendation, and the gain in accuracy is more than balanced by increased cost and loss of time. It is a well-known fact that small inaccuracies tend to balance each other, and that a line of levels covering 20 miles, taken with a self-reading rod, will closely check a line taken with target readings and rod level.

1288. How to Keep Level Notes.—Forms for keeping level notes are various. One of the best forms, rarely or never seen in print, and yet one which is in general use among engineers, is shown on the following page:

The distinguishing feature of this form of level notes is a single column for all rod readings. The backsights being additive and the foresights subtractive readings, they are distinguished from other rod readings by the characteristic signs + and −. The turning points, whose foresight reading is −, are further designated by the abbreviation T. P.

1289. How to Check Level Notes.—There is one method of checking level notes which is in universal use. It provides for checking the elevations of turning points and heights of instrument only, which is sufficient, as all other elevations are deduced from them. The method is very simple and depends upon the fact that all backsights

1. Station.	Rod Reading.	Ht. Instrument.	Elevation.	Grade	Cut.	Fill.	Remarks.	Date. 2.
B. M.	+ 5.61	105.61	100.00				On Root of White Oak	St'mp 10' L. Sta. 0
0	6.10		99.50					
1	7.30		98.30					
2	8.40		97.20					
3	9.20		96.40					
T. P.	− 10.22		95.39					
	+ 5.41	100.80						
4	5.30		95.50					
5	4.20		96.60					
5 + 50	11.50		89.30				Spring Brook	
T. P.	− 2.52		98.28					
	+ 11.57	109.85						
6	6.20		103.60					
7	8.50		101.30					
8	10.10		99.70					
T. P.	− 11.53		98.32					

are additive or + quantities, and all foresights are subtractive or − quantities. The level notes described in Art. **1288** are checked as follows: The elevation of the bench mark at Station 0 is 100.00 feet, to which all backsights or + readings are to be added, and from this sum all foresights or − readings are to be subtracted. The sum of the + readings or backsights together with the elevation of the bench mark at 0 is 122.59. The sum of the − readings or foresights is 24.27, and the difference 98.32 feet is the elevation of the turning point last taken. As soon as a page of level notes is filled, the leveler should check them, placing a check mark √ at the last height of instrument or elevation checked. When the work of staking out or cross-sectioning is being done, the levels should be checked at each bench mark on the line. At the close of each day's work, the leveler must check on the nearest bench mark.

	+	−
Thus,	100.00	10.22
	5.61	2.52
	5.41	11.53
	11.57	24.27
	122.59	
	24.27	
	98.32	

1290. Profiles.—A profile represents a vertical section of the line of survey. In it all abrupt changes in elevation are clearly outlined. Vertical and horizontal measurements are usually represented by different scales. Irregularities of surface are thus rendered more distinct through exaggeration. For railroad work profiles are commonly made to the following scales, viz., horizontal, 400 feet = 1 inch; vertical, 20 feet = 1 inch.

A section of profile paper is shown in Fig. 293. Every fifth horizontal line and every tenth vertical line is heavy. By the aid of these heavy lines, distances and elevations are quickly and correctly estimated and the work of platting greatly facilitated. The level notes described in Art. **1288** are platted in Fig. 293. The elevation of some horizontal line is assumed. This elevation is, of course, referred to the datum line, and is the base from which the other elevations are estimated. Every tenth station number is written

at the bottom of the sheet under the heavy vertical lines. The profile is first platted in pencil and then inked in black.

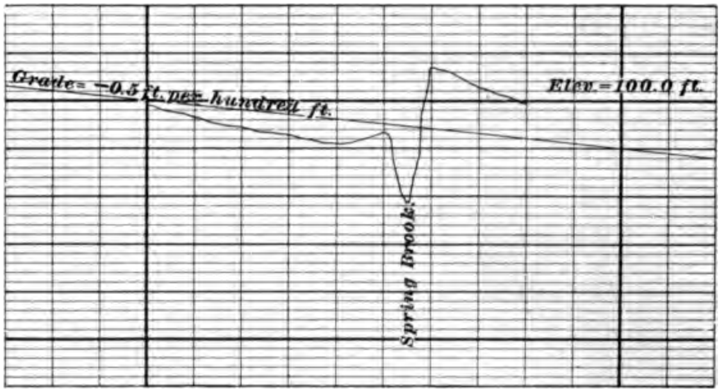


FIG. 293.

1291. Grade Lines.—The principal use of a profile is to enable the engineer to establish a **grade line,** i. e., a line showing the relative proportion of excavation and embankment in the proposed work. The **rate** of a grade line is measured by the vertical rise or fall in each hundred feet of its length, and is designated by the term per cent. Thus, a grade line which rises or falls 1 foot in each hundred feet of its length is called an ascending or descending 1 per cent. grade, and written + 1.0 or − 1.0 per hundred. A rise or fall of one-half foot in each hundred feet is called a five-tenths per cent. grade, and written + .5 or − .5 per hundred. The grade line having been decided upon, it is drawn in red ink.

EXAMPLE.—The elevation of Station 20 is 140.0 feet; between Stations 20 and 100 there is an ascending grade of .75 per cent.; what is the elevation of the grade at Station 71?

SOLUTION.—To obtain the elevation of the grade at Station 71, we add to the elevation of the grade at Station 20, 140 feet, the total rise in grade between Stations 20 and 71. Accordingly, $71 - 20 = 51$; .75 foot $\times 51 = 38.25$ feet; $140 + 38.25 = 178.25$ feet, the elevation of grade at Station 71.

TOPOGRAPHICAL SURVEYING.

1292. General Definition.—Topographical surveying is the location and representation of the inequalities of any portion of the earth's surface. The portion surveyed is conceived to be projected upon a horizontal plane, called a **plane of reference,** upon which all inequalities of surface as well as all conspicuous objects are shown in their true relative positions. The simplest and most generally used method of representing the **topography** of a given surface is by means of **contour lines.** A map containing an outline of a given surface, together with the contour lines representing its inequalities, is called a **contour map** of that surface.

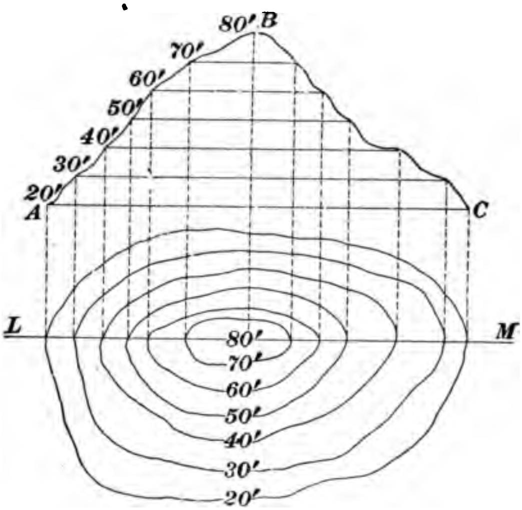


FIG. 294.

Let A B C, in Fig. 294, represent the outline of a hill, and suppose this hill to be gradually submerged in water, the water rising in successive heights of 10 feet. The flow, or shore line, at each successive rise is a **contour line.** The horizontal lines correspond to the surfaces of the successive elevations of the water. The points where these horizontal lines cut the edge of the hill are projected on the horizontal

line $L\ M$. The irregular lines connecting the corresponding points of projection are contours. In Fig. 294 they are assumed to be 10 feet apart in vertical measurement.

1293. Conduct of a Topographical Survey.—The manner of conducting a topographical survey will depend upon the extent and outline of the surface and the degree of accuracy required. If the area be of comparatively regular dimensions, such as town or park sites, the usual practice is to lay out the area in squares. The lines of division are the bases for the location of all points within the area whose elevations are determined by direct leveling. If the area is long and narrow, as in a railroad survey, the line of survey is the base for the location of all points and for determining their elevations. Cross-sections of the surface are taken at suitable intervals, and changes in the slope of the surface are measured either by direct leveling or with a *clinometer* or *slope board.*

1294. The Hand Level.—The usual form, called the "Locke level," from the name of the inventor, is shown in Fig. 295. It consists of a brass tube $A\ B$, on the top of which is a spirit level C. In the lower part of the tube is a

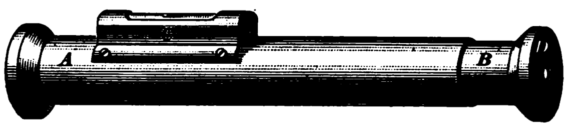


FIG. 295.

mirror which reflects the point at which the bubble should be when the instrument is level. A small hole D at one end and a cross-hair at the other give the level line. The observer holds the level to one eye, bringing it to a level line while he observes the object to which the level is directed with the other. In taking cross-sections with a Locke level, the following rule is recommended: The topographer has two or more assistants, three is the better number, a rodman and two tapemen. The rodman is provided with a rod at least 12 feet in length, of light weight, and of sufficient width to admit of large, distinct figures being painted upon

it, and divided to tenths of feet. The rod is painted like the Philadelphia rod; the face white, tenths of feet in black, and feet in red. Tapemen should use a tape 100 feet in length, of durable material. Chesterman with wire warp is best. The topographer first measures the distance of his eye above the ground, which is a constant quantity, to be subtracted from all the rod readings. He then stands at a station and keeps the rodman at right angles to the line of survey. The rodman, having reached the end of a slope, i. e., a point, where the rate of slope changes, he holds his rod at the point and the topographer takes the reading with the hand level. From this reading the topographer subtracts the constant, i. e., the height of his eye above the ground. The remainder is the difference between the elevation of the surface where the topographer stands and the surface where the rodman stands. The tapemen having measured the distance between the two points, the rate of slope is determined by dividing the distance measured by the difference in elevation. This method of taking slopes or cross-sections is illustrated in Fig. 296.

Let A be Station 156 of a preliminary survey. The topographer stands at A. The rodman goes to the point B,

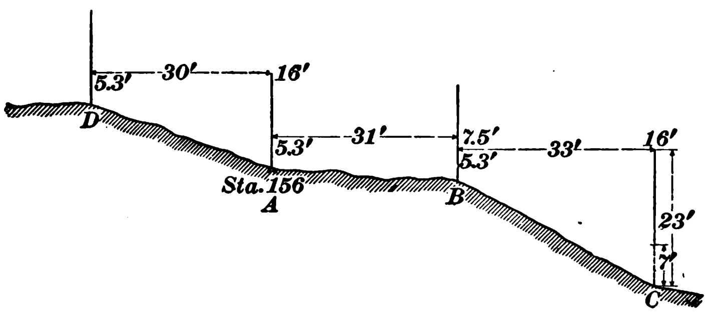


FIG. 296.

where the slope changes, holding his rod, which measures 16 feet in length, at that point. The topographer sights with his hand level and reads 7.5 feet on the rod. From this reading he mentally subtracts 5.3 ft., the height of his eye

above the ground. The remainder, 2.2 ft., is the difference in elevation between the points A and B. Meanwhile, the tapemen find that the horizontal distance from A to B is 31 feet. The rate of the slope $A\ B$ is the horizontal distance between the points A and B, 31 ft., divided by 2.2, their difference in elevation. The quotient is 14.1 and the slope is recorded $-\frac{2.2}{31}$. The topographer then moves to the point B, and the rodman goes to C, which is so much lower than B that with the rod held on the ground the line of sight will pass over the top of the rod. Here the rodman gives a "long" or "high" rod. Planting himself firmly at C, he raises the rod until the line of sight, from the topographer's eye, cuts the top of the rod, when the topographer calls "all right." He then notes where the bottom of the rod comes, and allows it to slide to the ground. Then adding to the length of the rod 16 ft., the distance from the ground to the point where the bottom of the rod came when the reading was taken, he calls out their sum to the topographer. In this example the rod is 16 feet and the addition 7 feet, making a high rod of 23 feet, which is common enough. The horizontal distance 33 feet, as measured by the tapeman, is also called out. The topographer makes the subtraction 5.3 from 23.0, and the difference 17.7 is written as the numerator of a fraction whose denominator is the horizontal distance 33. The slope being a descending one, the fraction will be $-\frac{17.7}{33}$, a slope of 1 to 1.9. In Fig. 296, the slopes $A\ B$ and $B\ C$ are **right slopes,** i. e., on the right side of the line of survey.

In taking the **left slopes,** the rodman and topographer change positions, the topographer going ahead and the rodman following. The topographer standing at D reads a rod of 16 feet held at A. Subtracting the constant 5.3, the remainder 10.7 is the difference between the elevations of A and D and is an ascending slope. The horizontal distance from A to D is 30 feet and the slope is recorded $+\frac{10.7}{30}$.

1295. Slope Angles.—Slopes are often measured with an instrument called a **clinometer,** which measures the angle which the line of slope makes with the horizontal, and is shown in Fig. 297. Tables are compiled giving the

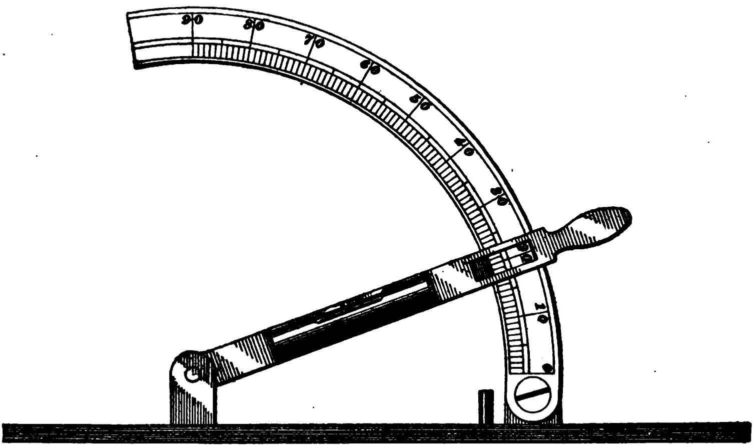


FIG. 297.

angle of slope and the horizontal distance for one foot of rise, as follows:

1° is 57.3 feet horizontal per 1 foot rise.
2° is 28.6 feet horizontal per 1 foot rise.
3° is 19.1 feet horizontal per 1 foot rise, etc.

1296. Platting Topography in the Field.—While some engineers favor the platting of contour maps in the field, the majority do not. To plat the map in the field, the topographer carries a case, the cover of which serves for a drawing board. The line of survey is divided into sections which are platted on different sheets, each sheet containing some of the immediately preceding section, so that by overlapping and pinning them together, a complete map of the line is obtained. The topographer carries in his case the sections covering his day's work, with the numbers and elevations of each station marked on the map. He pins a section to the cover of the case with thumb-tacks; his assistants measure the angle of the slope with a clinometer,

together with the horizontal distance; and from the table of slopes which he carries, the topographer determines the location of the contours and sketches them on the map. A better practice is to measure and record the slopes, keeping as close to the transit party as possible, and provide an extra man to work up the notes in the office under the direction of the topographer.

1297. Eye Measurements.—Though practice will greatly aid the eye in estimating distances, yet it is not to be relied upon when anything like exactness is required. In taking slopes, the length of the last one only may be estimated by the eye. More distant objects which lie without the possible range of location may be sketched in with the aid of the eye alone.

1298. Form of Topographer's Notes.—A good form for a topographer's notes is shown in the accompanying diagram :

Station.	Lt. Line.		Rt. Line.
0	$+\frac{8.4}{45}$ $+\frac{10.0}{30}$		$-\frac{11.4}{35}$ $-\frac{8.8}{50}$ for 100′
1	for 60′ $+\frac{11.5}{40}$		$-\frac{11.0}{53}$ $-\frac{7.0}{50}$ for 100′
2	for 60′ $+\frac{10.3}{40}$		$-\frac{11.5}{50}$ $-\frac{6.8}{55}$ for 100′
3	Same as 2	Center Line.	Same as 2
4	for 50′ $+\frac{11.8}{40}$		$-\frac{10.5}{55}$ $-\frac{7.5}{40}$ for 100′
5	for 50′ $+\frac{12.0}{35}$		$-\frac{11.3}{54}$ $-\frac{6.8}{40}$ for 100′
6	for 60′ $+\frac{10.4}{40}$		$-\frac{10.5}{50}$ $-\frac{7.5}{43}$ for 100′

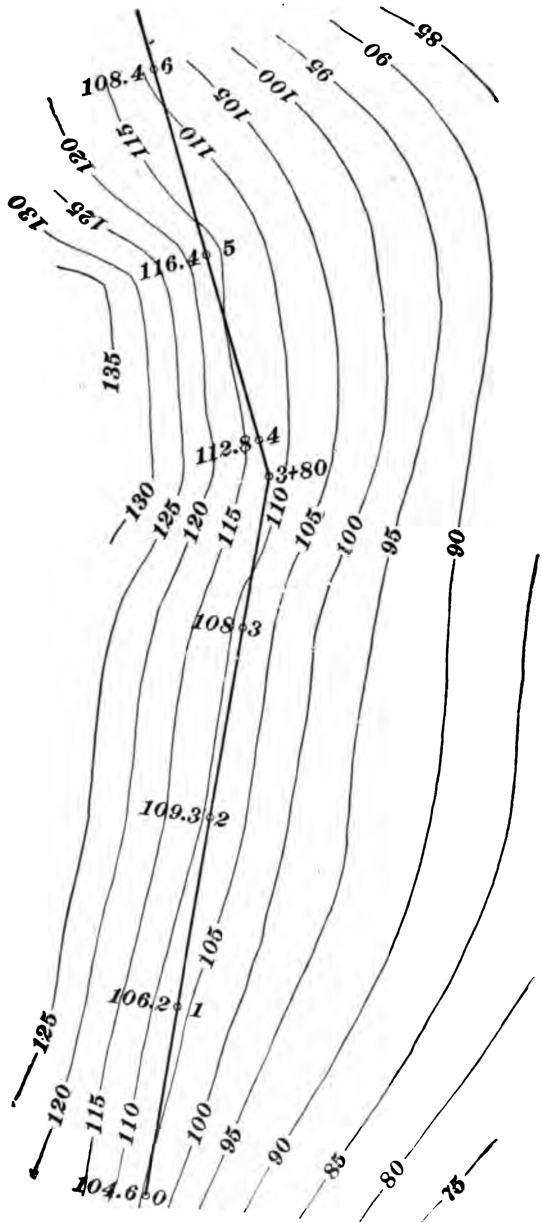

108.4
6
116.4
5
112.8
4
3+80
108
3
109.3
2
106.2
1
104.6
0
135
130
125
120
115
110
105
100
95
90
85
80
75

FIG. 298.

They are a record of the cross-sections or slopes of a preliminary railroad survey, the line of which extends along the side of a steep hill. The slopes are taken with a Locke level and rod, giving the actual differences in elevation between the points of change of slope. The alignment of the survey is shown in Fig. 298, and the contours are platted from the foregoing notes. The contours are 5 feet apart, i. e., the vertical rise between them is 5 feet.

The elevations of the stations the topographer has obtained from the leveler. The stations are marked on the plat, either by a dot, or, what is better, a dot enclosed in a small circle. The number of the station is marked at the right a little space ahead of the circle, the elevation on the left of the line and opposite to the number of the station. The cross-section lines are sometimes drawn on the map, very fine and at right angles to the center line, but usually the lines are omitted, the draftsman giving the true direction with his offset scale when locating the contours. In Fig. 298, the elevation of Station 0 is 104.6 feet. To reach the next contour above, viz., *105*, a rise of .4 foot must be made, and to reach the next lower contour a fall of 4.6 feet is necessary. From the notes, we find on the left of the line a rise of 10 feet in a horizontal distance of 30 feet or a rise of 1 foot in 3 feet, and for a rise of .4 foot we must go to the left of the line $.4 \times 3 = 1.2$ feet to contour *105*. To reach contour *110*, which is 5 feet higher, we must go $5 \times 3 = 15$ feet farther to the left. This distance added to 1.2, the distance to contour *105*, gives 16.2 feet, the second offset. We find by adding 10 feet (the rise in going 30 feet to the left of the line) to 104.6 feet, the elevation of Station 0, we have 114.6 feet, which is the elevation of the end of the first slope. An additional rise of .4 foot must be made in order to reach contour *115*. The second slope is a rise of 8.4 feet in a distance of 45 feet, or a rate of 1 foot in 5.4 feet. Multiplying 5.4 feet by .4, we have 2.2 feet, which is to be added to 30 feet, to reach contour *115*, and gives a distance of 32.2 feet. Contour *120* will be 5.4 feet $\times$ 5 = 27.0 feet beyond contour *115*, or 59.2 feet from the center line.

In the same way the contours to the right of the line are located. Tenths of feet are dropped in the computed distances, as they are too small for platting, and the nearest foot is taken.

Having located the contours by offsets for several consecutive stations, points of equal elevation are joined freehand, forming the contour lines, care being taken that lines of different elevation are kept distinct from each other and conforming to the curves and undulations of the original surface.

1299. Working Up Notes.—A good rule is to work up the notes for a considerable section before platting, thus avoiding the delay from continual change of work. The following form of working up notes is a good one, notes for each station being separated from those for other stations by a few strokes of a pencil. The example given is for Sta. 0, in Fig. 298.

Sta. 0. Elev. 104.6.

Rt. 14 feet to contour *100.*	Lt. 1 foot to contour *105.*
Rt. 29 feet to contour *95.*	Lt. 16 feet to contour *110.*
Rt. 53 feet to contour *90.*	Lt. 32 feet to contour *115.*
Rt. 81 feet to contour *85.*	Lt. 59 feet to contour *120.*
Rt. 110 feet to contour *80.*	
Rt. 137 feet to contour *75.*	

Contour lines are usually drawn first with pencil and afterwards inked in black. Short gaps are left in the lines at suitable intervals, in which their elevations are written. These should be of sufficient frequency to show at a glance the elevation of any contour.

Situations are continually recurring where the side slopes give but an inadequate idea of the topography. This is particularly true when the line of survey follows a stream with numerous tributaries and where highway crossings are frequent. In such cases the topographer will supplement the side slopes with free-hand sketches, which are invaluable helps in making topographical maps.

INDIRECT LEVELING.

1300. Indirect leveling is the process of determining elevations by either lines or angles or both. A common example in indirect leveling is given in Fig. 299.

Let DB be a flag-staff whose height is required. Set up a transit at A. Level carefully both the vernier plate and the telescope. The vertical arc will, if in adjustment, read at zero. Sight to C, the point where the horizontal line of sight strikes the flag-staff. Measure the distance $AC = 180$ feet, $CD = 4.2$ feet, and the diameter of the staff at $C = 1.5$ feet. Measure the vertical angle $CAB = 26° 10'$. From rule **5**, Art. **754**, we have $\tan A = \frac{CB}{AC + \frac{1}{2} \text{ dia. staff}}$. One-half diameter staff at $C = .75$ foot. Substituting known values, we have $\tan 26° 10' = \frac{CB}{180.75}$, whence $CB = 180.75 \times \tan 26° 10' = 180.75 \times .49134 = 88.809$ feet; $88.809 + 4.2 = 93.009$ feet $= DB$, the height of the flag-staff.

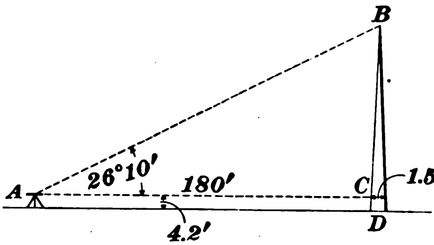


FIG. 299.

1301. Stadia Measurements.—The theory of the stadia is familiar to most engineers, yet comparatively few of them make any practical application of it, even when it would be greatly to their advantage.

In stadia work an ordinary leveling rod is generally used, and answers every purpose. It should be made of hard wood, such as mahogany, which is least affected by changes of temperature, and should be from 10 to 12 feet long, 2 inches wide, and about $1\frac{1}{4}$ inches thick. It is divided into feet, and each foot subdivided into tenths. The spaces corresponding to these latter divisions are painted alternately red and white, the number of tenths each space represents being painted in prominent black figures on the

lines of division. The space directly below each footmark should be inlaid with a mirror to reflect the light and enable the surveyor to read the rod at long distances with greater precision. The rod should also be provided with a sliding target. The best instrument to employ in this class of work is a transit reading to 30″. Besides the horizontal and vertical cross-wires which appear in the field of view of the ordinary transit telescope, the stadia transit is provided with two additional horizontal wires placed parallel with the horizontal wire in the plain transit, and at an equal distance above and below it, as shown in Fig. 300. These two extra wires are so placed that, if the stadia rod is held at a point 100 feet distant from the telescope, they will enclose 1 foot of the length of the rod. For example, if the lower wire coincides with the 4-ft. division, and the upper wire with the 5-ft. division of the rod, the distance from the center of the instrument to the rod will be 100 ft. + the *constant* for the particular transit used. The starting point for stadia measurements is often indiscriminately assumed to be either the center of the instrument, the center of the cross-wires, or from a plumb line dropped from the object glass; but, owing to the deflection of the sight due to the action of the lenses, the precise starting point for stadia measurements is a point as far in front of the object glass as its focal length; for example, if the focal length of the object glass is 6 inches, the starting point is 6 inches in advance of a plumb line dropped from the object glass. The distance from this point to the center of the instrument is "constant" for the *same* instrument, and must be added to the recorded stadia distance at every sight. In making a stadia survey, the transit should first be tested. Having found as level a plane as possible, test and adjust the level so that the vertical arc will read zero when the telescope is in a perfectly horizontal position; measure off very carefully from the center of the instrument, the short distance equal to the constant of the instrument, say 1.25 feet; from this point accurately measure a

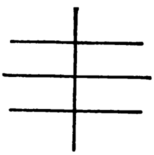


FIG. 300.

distance of 400 feet, driving a stake at each 100 feet. It is advisable to measure this test line with two or more steel tapes, and then take the average. As it will be necessary to test the cross-wires every few days, it is important that the test line should be conveniently located and very accurately measured. The line now measures 401.25 feet, as follows: First section, measuring from the center of the instrument, 101.25 feet, then three sections of 100 feet each, as shown in Fig. 301.

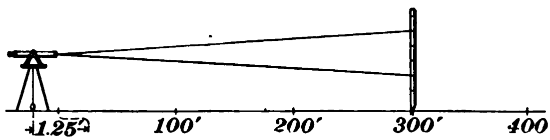


FIG. 301.

Direct the rodman to hold the rod on the point 201.25 feet from the instrument, and adjust the stadia wires so that they will include 2 feet on the rod. First adjust the upper to the center wire so as to include 1 foot, then adjust the lower to the center to include one foot. When this has been done, let the rod be held at the point 301.25 feet distant. The wires should now inclose 3 feet, 1.5 feet being included between the upper and center wires and 1.5 feet between the center and lower wires. Now test the point at the extremity of the line; the wires should at this distance include 4 feet. Instruct the rodman to hold the rod on the first point, 101.25 feet from the instrument, and if the stadia wires now include one foot, the instrument is in adjustment; if not, the operations must be repeated until the instrument reads correctly at every point. The ratio of the constant does not increase with the distance, but remains the same whether the distance of the sight be 50 or 2,500 feet.

At the beginning of a survey, the target on the rod is set at a height equal to that of the instrument, i. e., the distance from the ground-line to the axis of the telescope. This is done with the view of having the line of sight parallel with an imaginary line between the foot of the instru-

ment and the foot of the rod, which gives the exact vertical angle or degree of slope between the instrument and rod and a perfectly level plane. The rod is now held on a point where a sight is desired, and the transitman turns the telescope until the center wire and the center line of the target coincide; see Fig. 302. He then clamps the telescope, and reads the angle of elevation or depression, as the case may be, on the vertical arc, which is say 10° 26′; and, if the rod is held on a point at a greater elevation than that of the telescope, this angle will be one of elevation, and he will record it thus, + 10° 26′; but if the rod is held on a point lower than the instrument, the telescope will be correspondingly depressed, and the angle is recorded thus, − 10° 26′. The distance on the rod intercepted by the stadia wires is

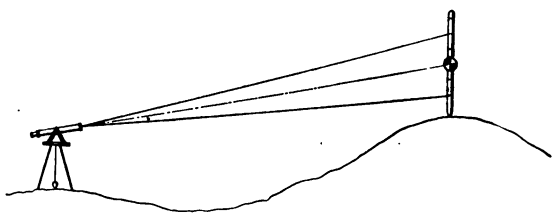


FIG. 302.

read and recorded. Assuming that the lower wire coincides with the 3.5 ft. division line, and the upper one cuts the rod at 7.46 feet, the intercepted distance is $7.46 - 3.5 = 3.96$ feet, and is thus recorded. The needle is next read, or, if it be an angular survey, the direction is platted and recorded. Having thus obtained the vertical angle, intercepted distance, and bearing, this sight is finished and the surveyor is ready to move to the next station.

Before any platting can be done, the distances must be calculated and reduced to the horizontal. This may be accomplished by means of the table of Horizontal Distances and Differences of Elevation for Stadia Measurements. In using the tables, proceed as follows: Look for the vertical angle, in this instance 10° 26′, and under the head Hor. Dist. find the number 96.72. Then, this number multiplied by

the distance intercepted by the stadia wires, viz., 3.96, equals $96.72 \times 3.96 = 383.01$; now, at the foot of the page, under 10° and opposite $c = 1.25$ (the constant of the instrument), find the corrected distance 1.23, which, added to 383.01, gives 384.24 feet, the corrected horizontal distance, which is recorded in the column provided for that purpose in the note book.

The difference of level is found thus: Under the head Diff. Elev., find 17.81, the number corresponding to the vertical angle $10^\circ\ 26'$. This number multiplied by the intercepted distance equals $17.81 \times 3.96 = 70.53$; at the foot of the column find .23, which, added to 70.53, gives 70.76 feet as the difference of elevation, and is recorded as such in its proper place. Proceed in the same manner to find the horizontal distances and differences of level of all the other points observed. The relative elevations of the various points observed, above or below any adopted datum line or plane of reference, can be readily determined by means of the signs + and – prefixed to each vertical angle recorded. Thus, assuming the survey to start from a B. M. 497.32 feet above the adopted plane of reference, and the first angle recorded to be, as before stated, $+10^\circ\ 26'$, corresponding to a difference of level of + 70.76 feet, the point observed will be $497.32 + 70.76 = 568.08$ feet above the datum plane. Where, however, boundary lines only are being run, it is unnecessary to compute the levels, but the vertical angles must be recorded in all cases, in order to correct the distances.

The calculations may be made, without the use of tables, in the following manner:

To obtain the horizontal distance, the following formula is employed:

$$D = c \cos n + a\ k \cos^2 n, \qquad \textbf{(94.)}$$

in which $D =$ the corrected distance; $c =$ the constant; $a\ k =$ the stadia distance, and $n =$ the vertical angle.

Assume, as before, a vertical angle of $+10^\circ\ 26'$ and an intercepted distance of 3.96 feet. As each foot of the rod intercepted by the stadia wires corresponds to a distance of

100 feet, an interception of 3.96 feet corresponds to a distance of 396 feet, called herein the stadia distance, i. e., the distance from the rod to the point outside the telescope where the stadia measurement begins.

Applying the formula, we have,

$$D = 1.25 \cos 10° 26' + 396 \cos^2 10° 26' =$$
$$125 \times .98347 + 396 \times .98347^2 = 384.24 \text{ ft.}$$

To obtain the difference of level E, apply the following formula:

$$E = c \sin n + a k \frac{\sin 2 n}{2}. \qquad \textbf{(95.)}$$

Applying this formula to the preceding example, we have $E = 1.25 \times .18109 + 396 \times .17810 = 70.75$, since $2 n = 10° 26' \times 2 = 20° 52'$ and $\frac{\sin 20° 52'}{2} = \frac{.35619}{2} = .17810$.

SURVEY OF BEAVER CREEK.

Station.	Station.	Dist.	Cor. Dist.	Bearing.	Vert. Angle.	Diff. Level.	Elevation above Tide.
0	1	396	384	N 1° 15 W	+ 10° 26′	+ 70.71	1142.21
1	*A*	201		Due E	+ 20° 11′		
1	*B*	404		S 80° 10 W	− 11° 14′		
1	*C*	187		S 76° 20 W	− 14° 22′		
1	*D*	563		S 68° 32 W	+ 3° 12′		
1	2	384		N 20° 15 W	− 0° 16′		

The tables of Horizontal Distances and Differences of Elevation for Stadia Measurements are computed for observations taken on a vertical rod held perfectly plumb.

Fig. 303 shows the method of keeping sketch and notes in topographical work.

1302. An efficient topographical survey is one which fully serves every purpose for which it is made. Its value depends more upon the accuracy of that which is represented rather than the minuteness or quantity of detail. The topographer should be able to readily and intelligently decide between what is important and what is not important, and invest his time and labor accord-

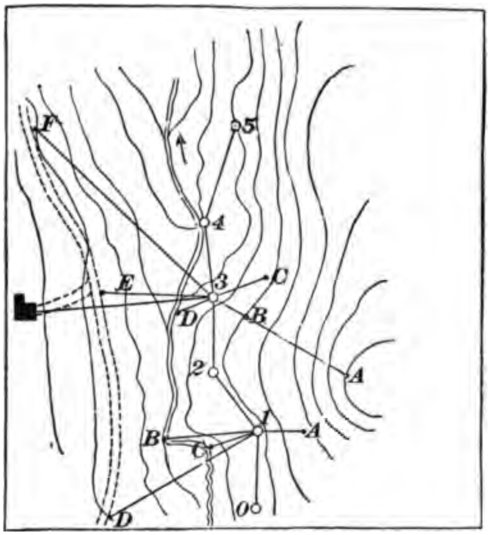


FIG. 303.

ingly, taking nothing for granted and never indulging in guesswork.

1303. The Aneroid Barometer.—Fig. 304 shows an aneroid barometer, a substitute for the mercurial barometer, which latter is not readily portable. It consists of a box of thin corrugated copper, exhausted of air. An increase in the weight of the atmosphere compresses the box, and a reduction in weight admits of the box being expanded by a spring inside. This spring is connected, by a system of levers, with a dial which indicates the pressure of the atmosphere. The face is graduated to correspond with the heights of the mercurial barometer. A thermometer is also

attached to the face and shows the temperature when the readings are taken.

FIG. 304.

1304. How to Determine Difference in Elevations With the Aneroid Barometer.—The formula given is that used by the Engineer Corps of the United States Army. The aneroid barometers used are adjusted to agree with the mercurial barometer at a temperature of 32° Fahrenheit at the sea level in latitude 45°. Observations at the two stations whose difference in elevation is required should be made as nearly simultaneous as possible, as temperature and atmospheric conditions are constantly changing.

Let Z = difference of elevation of the two stations in feet;

h = the reading in inches of the barometer at the lower station;

$H =$ the reading in inches of the barometer at the higher station;

t and $t' =$ temperature (Fahr.) of the air at the two stations.

Then,

$$Z = (\log h - \log H) \times 60{,}384.3 \times \left(1 + \frac{t + t' - 64°}{900}\right). \quad \textbf{(96.)}$$

EXAMPLE.—Reading at lower station, $h = 29.52$ in., $t = 70°$; at higher station, $H = 27.15$ in., $t' = 62°$.

$$\begin{aligned} \text{Log of } h,\ 29.52 &= 1.47012 \\ \text{Log of } H,\ 27.15 &= 1.43377 \\ \hline \text{Difference} &= \ .03635 \end{aligned}$$

$$1 + \frac{t + t' - 64}{900} = 1 + \frac{70 + 62 - 64}{900} = 1.0755.$$

Hence, $Z = .03635 \times 60{,}384.3 \times 1.0755 = 2{,}360.4$ feet, the difference between the elevations of the two stations.

Tables are prepared giving values of $(\log h - \log H) \times 60{,}384.3$ and of $1 + \frac{t + t' - 64°}{900}$, which greatly simplifies the work of determining differences of elevations.

HYDROGRAPHIC SURVEYING.

1305. Hydrographic surveying is the process of determining, by means of soundings, the location of the deep and shallow places of harbors, sounds, rivers, etc., and recording them in charts for the use of engineers and navigators.

1306. Sounding.—Sounding is measuring the depth of water. The surface of the water forms the datum line, and the various depths measure the undulations or changes of elevation of the bottom of the body of water being sounded. The extent of knowledge of the bottom gained will depend upon the number and accuracy of the soundings.

For depths to 18 feet, a sounding rod graduated to feet and tenths is used; for greater depths, a lead line, marked to fathoms and half fathoms, is employed. It will be found necessary to keep the lead line well stretched and its length frequently tested.

1307. Conduct of Survey.—The mode of conducting a hydrographic survey is as follows: Stations at conspicuous points on shore are first carefully located by trigonometrical surveying. They form the base line by which all irregularities of shore line and the location of all soundings are determined. A good station mark is a post set firmly in the ground with about one foot of its length exposed. A hole is bored in the center of the top of the post and a flagpole set in it. The pole can be pulled out and a transit set directly over the station. Each station should be distinguished by the combination of colors on the flag, and the number of the station should be distinctly marked on the post. A permanent bench mark must be established and the height of water at the time of the soundings recorded.

Buoys are made of light wood, and painted in such colors as will make them conspicuous.

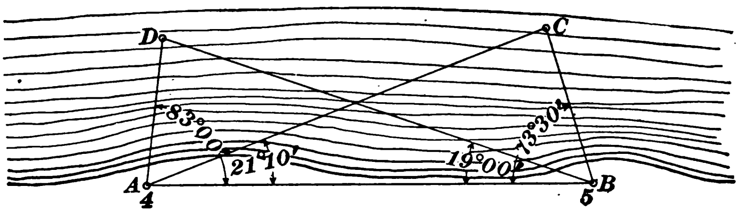


FIG. 305.

The location of buoys and soundings is illustrated in Fig. 305. The stations *A* and *B* are located and their distance apart known. A transit is set up at each station and back-sighted to a rod at the other; the vernier plate is then unclamped and the leadsman in the boat is carefully followed with the instrument. At a given signal, the leadsman takes a sounding, and both instruments sight to him and read the angles, which give a side and two adjacent angles of a triangle from which to determine the location of the point *D*. In the same manner *C* and any number of points can be located. A man in the boat records the time and the soundings as they are read by the leadsman.

1308. Tide Gauges.—By means of a tide gauge the height of water at any time may be known. The datum or zero line is mean low spring tide. A simple form of tide gauge is a board nailed to the upright front of a dock. The face should be painted white and graduated to half-feet or to feet and tenths, and the zero line set at mean low spring tide. The feet marks should be in heavy black figures, so that they may be easily read.

The tide gauges used by the government are automatic, and are provided with an indicator which registers on paper the fluctuations of the tide.

LAND SURVEYING.

1309. The United States System of Surveying Public Lands.—The public lands of the United States are divided and laid out into approximately equal squares, the sides of which are true north and south or east and west lines. This is effected by means of meridian lines and parallels of latitude established six miles apart. The squares thus formed are called **townships,** and contain 36 square miles or **sections.** Each section contains, as nearly as may be, 640 acres, giving an approximate area of 23,040 acres for each township.

1310. Principal Meridians.—A **principal meridian** running due north and south and a **base line** running due east and west are established astronomically, and the half-mile, mile, and six-mile corners are permanently marked on them. These two lines form the basis of all subsequent divisions into townships and sections. All other lines, with the exception of these two and the standard parallels, are run with the compass and chain.

Fig. 306 represents a section of country thus laid out. The scale is 10 miles to 1 inch = 633600 : 1. The diagram shows the principal meridian running truly north and south, and a base line which is a **parallel of latitude** running truly east and west. Parallel to these are other lines 6 miles apart, forming townships. All the townships situated north or south of each other form a **range,** the ranges being named by their number east or west of the principal meridian. The seven ranges east and seven west of the principal meridian, shown in Fig. 306, are described as R. 1 E, R. 1 W, etc. The townships in each range are designated by their number north or south of the base line. Thus, in the diagram,

the township marked *A* is denoted by T. 3 N, R. 4 W; that marked *B*, by T. 2 S, R. 3 E. These abbreviations should

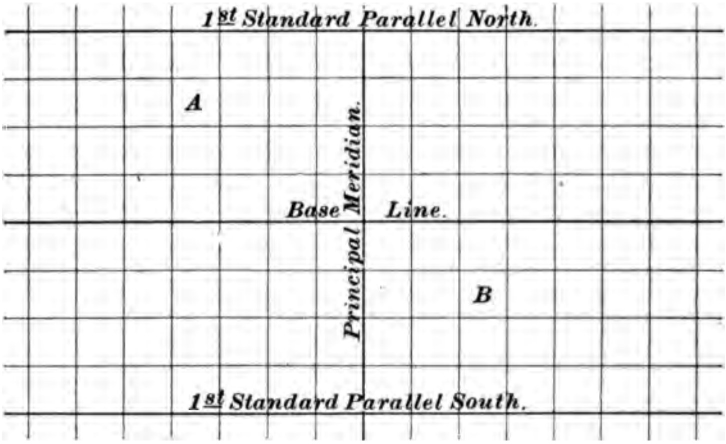


FIG. 306.

be read *township 3 north, range 4 west, and township 2 south, range 3 east.*

1311. Township Divisions.—Each township is divided into 36 sections, each one mile square and containing 640 acres as nearly as may be. The sections in each township are numbered from *1* to *36*, as shown in Fig. 307. The numbering of the sections begins at the northeast corner of the township and goes west from *1* to *6*, then east from *7* to *12*, and so on alternately until section *36* in the southeast angle of the township is reached. The sections are subdivided into quarter-sections, each half a mile square and

N

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

W E

S

FIG. 307.

containing 160 acres, and sometimes into half quarter-sections of 80 acres and quarter quarter-sections of 40 acres. By this system the smallest subdivision of land can be accurately located; as, for example, the southeast quarter of section *36* in township one south in range two west of Willamette meridian.

1312. Obstacles.—The law requires that the lines of the public surveys shall be governed by the true meridian, and that the townships shall be six miles square, two conditions involving a mathematical impossibility, for strictly conforming to the meridian would necessarily throw the township out of square, for the reason that a degree of longitude, which, at the equator, is $69\frac{1}{6}$ miles, constantly diminishes as one approaches the poles. As the meridian lines are strictly adhered to, the requirements of the law respecting areas are not fulfilled. The townships assume a trapezoidal form which increases the higher the latitude of the surveys. To meet these conditions the law provides that the sections shall contain 640 acres, as nearly as may be, and further provides that "in all cases where the exterior lines of the township thus to be subdivided into sections and half-sections shall exceed or shall not exceed six miles, the excess or deficiency shall be specially noted and added or deducted from the *western* or *northern* ranges of sections or half-sections in such township, according as the error may be in running the lines from east to west or from south to north." In order to throw the excesses or deficiencies, as the case may be, on the *north* and *west* sides of a township, according to law, it is necessary to survey the section lines from south to north on a true meridian, leaving the result in the northern line of the township to be governed by the convexity of the earth and the convergency of meridians.

Thus, suppose the land to be surveyed lies between 46° and 47° of north latitude. The length of a degree of longitude in latitude 46° north is taken as 48.0705 statute miles, and in latitude 47° north as 47.1944 miles. The difference, or convergency per square degree, = .8761 mile =

70.08 chains. The convergency per range (8 per degree of longitude) equals one-eighth of this distance or 8.76 chains, and per township ($11\frac{1}{2}$ per degree of latitude) will equal 8.76 chains divided by $11\frac{1}{2} = .76$ chain. Hence, we know that the width of townships along their northern boundary is 76 links less than on their southern boundary. The townships north of the base line, therefore, become narrower and narrower than the six-mile width with which they start by that amount.

1313. Standard Parallels.—Standard parallels, called **correction lines,** are established at intervals of 24 miles to provide for the correction of the error arising from the convergency of the meridians. They also serve to limit errors resulting from inaccuracies in measurement. Such correction lines when lying north of the principal base line form new base lines for the surveys north of them. The convergency or divergency is taken upon these correction lines, from which, as base lines, the townships start again with their proper widths. On these correction lines, therefore, *double corners* will be found, one set being the *closing corners* of the surveys *ending there*, and the other set the *standard corners* of the surveys *starting there.*

1314. Running Township Lines.—The principal meridian, the base line, and the standard parallels having been first astronomically run, measured, and marked according to instructions on true meridians and true parallels of latitude, the process of running, measuring, and marking the exterior lines of townships is as follows:

For townships *north* of the *base line* and *west* of the *principal meridian*, commence at Station No. *1* (Fig. 308), the southwest corner of T. 1 N, R. 1 W, as established on the base line, thence run *north* on a true meridian line 480 chains, establishing the half-mile and mile corners thereupon, according to instructions, to No. *2*, which is the northwest corner of the same township. There establish the corner of townships 1 and 2 N, ranges 1 and 2 W; thence run *east* on a *random* or trial line, setting temporary stakes

at the half-mile and mile points and noting the distance where the line intersects the eastern boundary north or south of the *true* or established corner. Run and measure *westward* on the *true* line, establishing permanent half-mile and mile corners, noting all water crossings and the character of the land, as per instructions, to No. *4*, which is identical with No. *2*. The last half-mile will fall short of

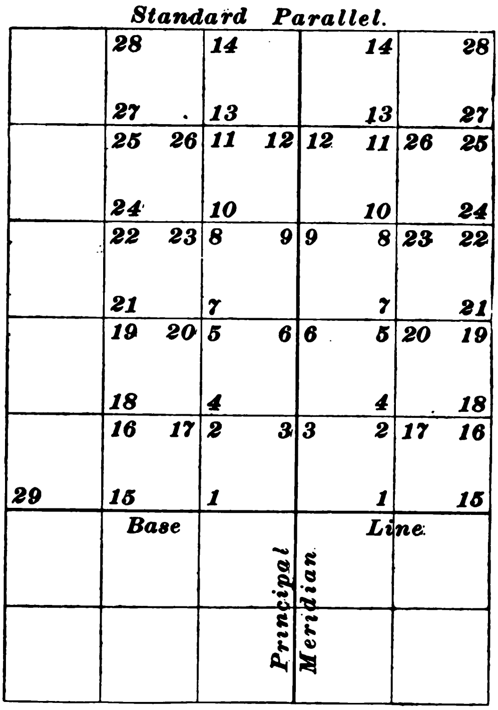


FIG. 308.

40 chains by about the amount of the calculated convergency per township, which, in the above supposed case, equals 76 links.

The terms random and true lines are explained in Fig. 309. The boundary from Station *1* to Station *2* is a true meridian and 480 chains in length, with *permanent* corners set at each half-mile and mile. From *A* run and measure

towards B on a true east and west line, as shown by the dotted line A B, which is called a **random line,** setting temporary half-mile and mile posts. This random or trial line being run on a parallel of latitude, must intersect the principal meridian near the true corner C, previously established. The return or true line always connects this true corner with the one from which the random starts. Random lines

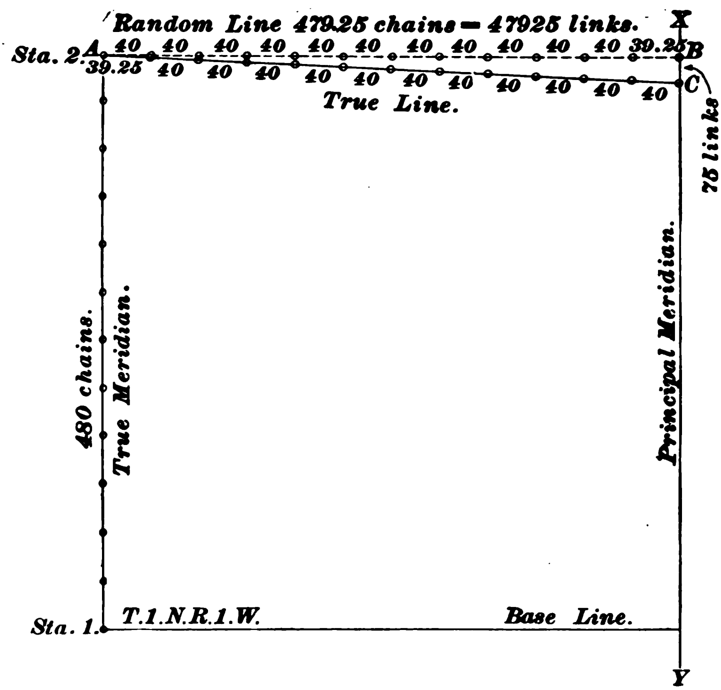


FIG. 309.

are either true east and west or true north and south lines, i. e., they are either parallels of latitude or true meridians. Suppose the random line intersects the principal meridian X Y at B, 75 links to the north of the true or established corner at C, the length of A B is 479 chains and 25 links. The triangle A B C is a right-angled triangle, right angled at B; dividing B $C = 75$ links by A $B = 47925$ links, we have the tangent of the angle B A $C = \frac{75}{47925} = .00156 =$

tan 0° 05′. The angle $B\ C\ A$ is, therefore, $90° = 0°\ 05' = 89°\ 55'$, and the return course, or true line, $C\ A$ is N 89° 55′ W. Setting the instrument over the true or established corner C, the compass is set for the true course $C\ A$, N 89° 55′ W, and measuring 40 chains from C, a permanent half-mile or quarter-section post is set, 40 chains further a mile or section post is set, and so on, setting half-mile and mile posts at regular intervals of 40 chains until the last half-mile post is set; between it and the township corner A, the distance is but 39 chains and 25 links, thus leaving the deficiency in the western tier of sections as prescribed by law.

In case the random line materially falls short, or overruns in measurement, or intersects the eastern boundary at a considerable distance from the established corner, it will be evident that there has been considerable error either in direction or measurement of the lines, or both, and the lines must be *retraced* even if it should be found necessary to rerun the meridianal boundaries of the township (especially the western boundary) so as to discover and correct the error. The true corners must be established, and the false ones destroyed and obliterated, and all facts carefully set forth in the notes so as to avoid future confusion.

Then proceed north from *4* to *5*, establishing corners as before; No. *5* is the N W corner of T. 2 N, R. 1 W; east to No. *6* (the N E corner of the same township), west to No. *7* (the same as No. *5*), north to No. *8* (the N W corner of T. 3 N, R. 1 W), east to No. *9* (the N E corner of the same township), west to No. *10* (same as No. *8*), north to No. *11* (the N W corner of T. 4 N, R. 1 W), east to No. *12* (the N E corner of the same township), west to No. *13* (same as No. *11*), and thence north on a true meridian to the standard parallel or correction line (which is here five townships, or 30 miles, north of the base line), throwing the difference over or under four hundred and eighty chains on the last half mile, according to law. At the intersection with the standard parallel establish the *closing corner*, the distance of which from the standard corner must be

measured and noted as required by the instructions. In case any obstruction should have prevented the extension of the standard parallel along the field of the present survey, the surveyor will establish a corner for the township, subject to correction, should the parallel be extended. The surveyor then returns to the base line, and, from the southwest corner of T. 1 N, R. 2 W, carries up another tier of townships, closing as before.

For townships *north* of the base line and *east* of the principal meridian the order of survey is as follows: Beginning at the southeast corner of T. 1 N, R. 1 E, proceed as with townships *north* and *west*, except that the trial or random line is run and measured *west* and the **true line** *east*, throwing the difference over or under 480 chains on the *west* end of the line. Accordingly, the surveyor, having measured his trial line west, will first determine the length of the last half-section line, and commence the measurement of the true line with such excess or deficiency, and, consequently, the remaining measurements will all be exact half miles and miles.

1315. Running Section Lines.—The interior or sectional lines of all townships, however situated with reference to base and meridian lines, are laid off and surveyed, as shown in Fig. 310.

In this figure the squares and large figures represent sections; the small figures are referred to in the following directions. Commence at No. *1* (see small figure in the diagram) which is a township boundary for sections *1*, *2*, *35*, and *36*; thence run *north* on a true meridian; at 40 chains establish a half-mile or quarter-section post, and at 80 chains establish the corner of sections *25*, *26*, *35*, and *36*. Thence *east* on a *random line* to No. *3*, setting a temporary quarter-section post at 40 chains, noting the measurement to No. *3* and the distance of the random's intersection north or south of the true or established corner of sections *25*, *36*, *30*, and *31*. Thence *correct west* on a *true line* to No. *4*, setting the quarter-section post on this line *equidistant* from the two

corners whose distance apart is now known. In like manner proceed from *4* to *5*, *5* to *6*, *6* to *7*, and so on to No. *16*, the corner of sections *1*, *2*, *11*, and *12*, thence *north* on a *random line* to No. *17*, setting a temporary quarter-section post at 40 chains and noting the length of the whole line and the distance of the *random's* intersection east or west of the true corner of sections *1*, *2*, *35*, and *36* established on the township boundary, then *southwardly* from the latter on a true

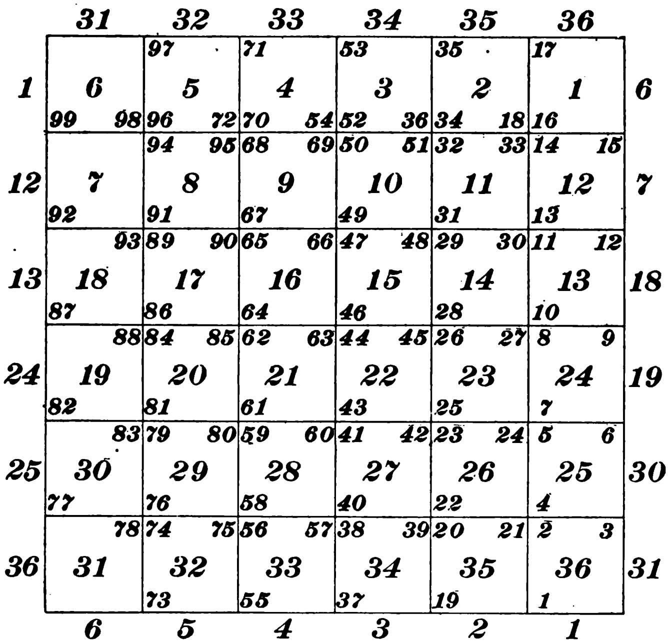


FIG. 310.

line, noting the *course* and distance to No. *16*, the established corner to sections *1*, *2*, *11*, and *12*, care being taken to establish the quarter-section post at 40 chains from said section corner, thus throwing the excess or deficiency on the northern half mile, according to law. Proceed in like manner through all the intervening tiers of sections to No. *73*, the corner of sections *31*, *32*, *5*, and *6*. Thence north on a true meridian 80 chains to *74*, setting a quarter-section post at

40 chains, and at 80 chains setting corner of sections *29*, *30*, *31*, and *32*; then east on a random to *75*, setting temporary quarter-section post at 40 chains, noting the entire measurement to the eastern boundary and the distance of the random's intersection north or south of the true corner of sections *28*, *29*, *32*, and *33*; thence west on a true line, setting the quarter-section post on the true line and equidistant from either end, to No. *76*, which is identical with *74*; thence west on a random line to *77*, setting temporary quarter-section post at 40 chains, noting the full measurement of the line and the distance of the random's intersection with the township boundary *north* or *south* of the established corner of sections *30*, *31*, *25*, and *36*; thence eastwardly on the true line, *giving its course* and setting the quarter-section post 40 chains from the corner of sections *29*, *30*, *31*, and *32*, thus throwing the excess or deficiency of measurement on the western half mile of the section according to law. Proceed *north* in like manner from No. *78* to *79*, *79* to *80*, *80* to *81*, and so on to No. *94*, the southeast corner of section *6*, where, having established the corner of sections *5*, *6*, *7*, and *8*, run thence successively the random line *east* to *95*, *north* to *97*, and *west* to *99*, and by reverse courses *back on true lines* to the southeast corner of section *6*, establishing the quarter-section corners, and noting *courses*, measurements, and distances as prescribed by law.

In townships contiguous to standard parallels the above method is varied as follows: In every township *south* of the principal *base line* which *closes* on a standard parallel, the surveyor will begin at the southeast corner of the township and measure westward, establishing the half-mile and mile corners and noting their distance from the preestablished corners. He will then proceed to subdivide as directed under the above head.

In townships *north* of the *principal base line* which *close* on the standard parallel, the section lines must be closed on the standard parallel with true *meridian lines* instead of *course* lines, as directed for townships otherwise situated; and the connections of the closing corners with the

preestablished standard corners are to be ascertained and noted.

In case the surveyor is unable to close the lines on account of the standard not having been run for some reason, as before mentioned, he will then plant a temporary post or construct a mound at the end of the *sixth* mile, thus leaving the lines and their connections to be finished when the standard shall have been run.

1316. Water Frontage.—Departures from the general system of dividing land have been authorized by law, especially in the case of water frontage.

In surveying the public lands of Louisiana, which border on rivers, streams, lakes, and bayous, surveyors were authorized to divide the land with water frontages of fifty-eight poles and running back four hundred and sixty-five poles in depth, "and of such shape and bounded by such lines as the nature of the country will render practicable and most convenient." Later, authority was given to survey lands with two acres water frontage and running back a depth of forty acres, tracts so surveyed to be offered for sale entire instead of in half quarter-sections. In localities where it would best subserve the interests of the people to have fronts on the navigable streams and running back into the uplands for timber, surveyors were authorized to increase the quantity of land so as to give four acres frontage and forty acres in depth, giving tracts of 160 acres, but in so doing they were only to survey the lines between *every four lots* (or 640 acres), establishing the boundary posts or mounds *in front* and *in rear*, at the distances requisite to secure the quantity of 160 acres to each lot, either rectangularly where practicable or at oblique angles where otherwise. The angle is not important so long as the principle is adhered to of making, as far as possible, the rear lines square with the regular sectioning.

1317. Meandering.—This name is applied to the usual mode of traversing or surveying a navigable stream. The instructions for this work are in part as follows: Both

banks of *navigable* rivers are to be meandered by taking the courses and distances of their sinuosities and the same are to be entered in the *meander* field book. At those points where either the township or section lines intersect the banks of a navigable stream, posts, or, where necessary, *mounds of earth or stone* are to be established at the time of running these lines. These are called "meander corners," and, in meandering, the surveyor will commence at one of these corners on the township line, coursing the banks and measuring the distance of each course from the commencing corner to the next "meander corner" upon the same or another boundary of the same township, carefully noting intersections with all the intermediate meander corners. By the same method meander the opposite banks of the river.

The crossing distance *between* the *meander corners* on the same line is to be ascertained by triangulation, in order that the river may be protracted with entire accuracy. The particulars are to be given in the field notes. The courses and distances on meandered navigable streams are the bases for the calculation of the true areas of the tracts of land (sections, quarter-sections, etc.), known to the law as *fractional* and bounding on such streams.

The surveyor is also to meander, in manner aforesaid, all lakes and deep ponds of the area of twenty-five acres and upwards, also navigable bayous.

As traverse tables are generally calculated to 15′ angles, it is advisable to make meander courses read to quarter degrees instead of intermediate minutes, except in closing or where the extreme length of a side of a lake or stream falls in one course.

The precise relative position of islands in a township made fractional by the river in which they are situated is to be determined trigonometrically. To meander islands crossed by government lines, meander corners are previously established at opposite points on the shore of the island, and the meanders run from one to the other. Should the island not be crossed by a line, measure a special base line from the

meander corner nearest to the island, triangulating to and establishing at any convenient point on the island a special meander corner from and to which the meanders of the island start and close.

1318. Marking Lines.—All lines on which are to be established the legal corner boundaries are to be marked after this method, viz.: Those trees which may intercept the line must have two chops or notches cut on each side of them without any other marks whatever; these are called *sight trees* or *line trees*. A sufficient number of other trees standing nearest to the line on either side of it are to be *blazed* on two sides diagonally or quartering towards the line, in order to render the line conspicuous and readily traced, the blazes to be opposite to each other, coinciding in direction with the line where the trees stand very near it, and to approach nearer each other the further the line passes from the blazed trees. Due care must ever be taken to have the line so well marked as to be readily followed.

1319. Marking Corners.—After a true coursing and most exact measurements, the corner boundary is the consummation of the work for which all the previous pains and expenditure have been incurred. A boundary corner in a timbered country is to be a *tree*, if one be found at the precise spot; and if not, a *post* is to be planted thereat, and the position of the corner post is to be indicated by trees adjacent (called bearing trees), the angular bearings and distances of which from the corner are facts to be ascertained and recorded by the surveyor. In a region where stones abound, the corner boundary will be a small monument of stones alongside of a single marked stone for a township corner and a single stone for all other corners.

In a region where neither timber nor stone is available, the corner will be a mound of earth of prescribed size varying to suit the case.

When *posts* are used, their length and size must be proportional to the importance of the corner, whether township, section, or quarter-section post.

Township corner posts are three inches square and set at least twenty-four inches above ground.

Where a township post is at a corner, common to *four* townships, it is to be set in the ground diagonally, as shown in Fig. 311, and the cardinal points of the compass indicated by lines cut or sawed out of its top at least one-eighth of an inch deep, as shown in the figure. On each face of the post is to be marked the number and range of the particular township which it *faces*. Thus, if the post be a common boundary to four townships, viz., one and two south of the base line and range two west, and also one and two south of the base line and range three west, the face markings will be as follows:

FIG. 311.

$$\text{From N to E}\left\{\begin{array}{c}\text{R. 2 W}\\ \text{T. 1 S}\\ \text{S 31}\end{array}\right\}$$

$$\text{From N to W}\left\{\begin{array}{c}\text{3 W}\\ \text{1 S}\\ \text{36}\end{array}\right\}$$

$$\text{From E to S}\left\{\begin{array}{c}\text{2 W}\\ \text{2 S}\\ \text{6}\end{array}\right\}$$

$$\text{From W to S}\left\{\begin{array}{c}\text{3 W}\\ \text{2 S}\\ \text{1}\end{array}\right\}$$

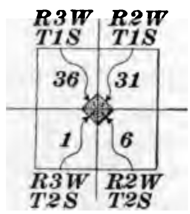


FIG. 312.

The position of the post which is here taken as an example is shown in Fig. 312.

These marks are neatly chiseled into the wood, and are also marked with *red chalk.* The *number* of the *sections* which they respectively *face* will also be marked on the township post.

Section or mile posts, being corners of sections, when they are common to four sections, are to be set *diagonally* in the earth (in the manner provided for township posts), and with similar marks cut in the top to indicate the cardinal points of the compass, while on *each side* of the post is

cut the number of the *particular section* which the side faces. Also, on one side is to be marked the number of its township and range. To make such marks more conspicuous and durable, red chalk is applied. A quarter-section or half-mile post is to have no other mark than ¼ S to indicate what it stands for.

Township posts are to be *notched* with *six* notches on each edge or angle corresponding to the cardinal points of the compass. All mile posts on township lines must have as many notches on opposite angles as they are miles distant from the corresponding township corners. Each of the posts at the corners of sections in the interior of a township must have on their four angles, corresponding to the cardinal points, as many notches as they are miles distant from the corresponding township corners. The four sides of the post will indicate the numbers of the sections which they respectively face. Should a tree be found at the place of any corner it will be marked and notched in the manner before described and will serve in place of a post; the kind of tree and the diameter must be given in the field notes.

The position of all corner posts or corner trees of whatever description, which may be established, is to be perpetuated in the following manner, viz.: From such post or tree, the courses shall be taken and the distances measured to two or more adjacent trees in opposite directions as nearly as may be, which are called *bearing trees*, and are to be blazed near the ground with a large blaze facing the post and having one notch in it, neatly and plainly made with an ax, square across, and a little below the middle of the blaze. The kind of tree and the diameter of each are facts to be clearly set forth in the field book.

On each bearing tree the letters B. T. must be distinctly cut into the wood in the blaze a little above the notch or on the bark, with the number of the range, township, and section.

At all township corners and at all section corners on range or township lines *four* bearing trees are to be marked in this manner, one in each of the adjoining sections.

At interior section corners *four* trees, one to stand within *each* of the four sections to which such corner is common, are to be marked in the manner aforesaid if such be found.

From quarter-section and meander corners, two bearing trees are to be marked, one within each of the adjoining sections. Stones at township corners (a small monument of stones being alongside thereof) must have *six* notches cut with a pick or chisel on each edge or side towards the cardinal points; and where used as corners in the interior of a township, they will also be notched with a pick or chisel to correspond with the directions given for notching posts similarly situated.

Stones when used as quarter-section corners will have ¼ cut on them, on the *west* side in *north* and *south* lines, and on the *north* side in *east* and *west* lines.

Wherever bearing trees are not found, *mounds* of earth or stone are to be raised *around posts* on which the corners are to be marked in the manner aforesaid. Wherever a mound of earth is adopted, the same will present a pyramidal shape. At its base on the earth's surface a *quadrangular trench* will be dug; a spade deep of earth being thrown up from the sides of the line *outside* the trench, so as to form a *continuous elevation along its outer edge.* In mounds of earth common to four townships or four sections, they will present the angles of the quadrangular trench *diagonally* to the cardinal points. In mounds common only to *two* townships or *two* sections, the sides of the trench will face the cardinal points. Prior to piling up the earth, in a *cavity*, formed at the corner boundary point, is to be deposited a *stone*, or a portion of charcoal; or a charred stake is to be driven twelve inches down into such center point to be a witness for the future. The surveyor is further specially enjoined to plant midway between each pit and the trench seeds of some tree, those of fruit trees adapted to the climate being always to be preferred.

Double corners are to be found nowhere except on the standard parallels or correction lines whereon are to appear

both the corners which mark the intersection of the lines which close thereon and those from which the surveys start in the opposite direction.

The corners which are established on the standard parallel at the time of running it are to be known as "*standard corners*," and in addition to all the ordinary marks (before described) they will be marked with the letters S. C. The *closing corners* will be marked C. C.

1320. Field Books.—There are several field books, viz.:

1. Field Books for the meridian and base lines, showing the establishment of *township*, *section*, or mile, and *quarter-section*, or half-mile boundary corners thereon; with the crossings of streams, ravines, hills, and mountains; the character of the soil, timber, minerals, etc. These notes will be arranged in series by *mile stations* consecutively from number one to number ——.

2. Field Books for the *standard parallels* or correction lines, showing the establishment of the township, section, and quarter-section corners, besides exhibiting the topography of the country on line as required on the base and meridian lines.

3. Field Books for exterior lines of townships, showing the establishment of the corners on line, and the topography as aforesaid.

4. Field Books for the subdivision of townships into sections and quarter-sections; at the close whereof will follow the notes of the meanders of navigable streams. Those notes will also show by ocular observation the estimated rise and fall on the line. A description of the timber, undergrowth, surface soil, and minerals upon each section line is to follow the notes thereof, and not be intermixed with them.

5. The Geodetic Field Book, comprising all triangulations, angles of elevation and depression, leveling, etc.

1321. Retracing Old Lines.—The original surveys of lands in the older States of the American Union were

imperfectly made and full of errors. This was owing to two principal causes; viz., the cheapness of the lands and the lack of skill in the surveyors. Boundary lines described in deeds and shown in maps as straight are found to be crooked on the ground; tracts contain less or more land than called for in descriptions. Records of adjoining tracts make one to overlap another or leave an unclaimed gore between them. These discrepancies and blunders often render the work of the surveyor, when retracing old boundaries or establishing corners, exceedingly difficult, and great tact and judgment are often necessary in making amicable and satis-

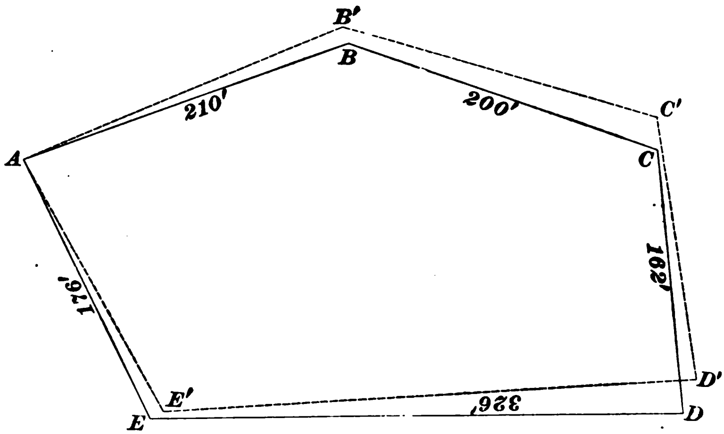


FIG. 313.

factory adjustments of contending claims. In general, old boundaries, such as line trees, stone monuments, and fences are accepted as holding ; but, before retracing lines the surveyor should, if possible, secure the consent of adjacent owners to abide by such monuments and boundaries, irrespective of the lines or quantities called for in contracts or deeds. It must be borne in mind that the bearings of lines are each year undergoing a slight change which, in a long period, amounts to several degrees, and if the lines were rerun according to original bearings as given in descriptions, they would enclose a tract differing widely from that included in the original survey. The surveyor must accord-

ingly determine the amount of magnetic variation or change which has taken place between the time of the original survey and the date of the survey about to be made, and having determined such change or variation, he must make the original bearings conform to the calculated variation before commencing the survey.

Fig. 313 illustrates the effect of magnetic variation in altering the direction of lines. The figure $A\ B\ C\ D\ E$ gives the outline of a tract according to the original survey, and $A\ B'\ C'\ D'\ E'$ the relative directions of the boundaries when resurveyed with the original bearings, there having been during the intervening time a change in magnetic variation of 3° west.

Let columns 1, 2, and 3 in the accompanying diagram give the courses, original bearings, and distances, and column 4 the corrected bearings which the original boundaries will have, when allowance has been made for the magnetic variation. When the north end of the needle has been moving westerly, i. e., when the variation or *change* is *west*, the *corrected* or *present bearings* will be the *sums* of the change and the old bearings which were *northeasterly* or *southwesterly* and the *differences* of the change and the old bearings which were *northwesterly* or *southeasterly;* when the variation or change is *easterly*, the corrected or present bearings will be the *differences* of the change and the old bearings which were *northeasterly* or *southwesterly* and the *sums* of the change and the old bearings which were *northwesterly* or *southeasterly*.

1 Courses.	2 Bearings.	3 Distances.	4 Corrected Bearings.
A B	N 68° 00′ E	210	N 71° 00′ E
B C	S 73° 00′ E	200	S 70° 00′ E
C D	S 8° 00′ E	162	S 5° 00′ E
D E	S 87° 00′ W	326	S 90° 00′ W
E A	N 28° 00′ W	176	N 25° 00′ W

It will be seen, by reference to Arts. **1211** and **1212**, that *declination* is the reverse of *variation*, i. e., a *west* declination results when the variation or movement of the N end

of the needle is to the east, and *east* declination results when the movement of the N end of the needle is to the west. By this rule the bearings given in column 4 are obtained. Before commencing the survey, the surveyor should correct all the bearings and write them out together with the original bearings in their proper order.

1322. How to Determine Magnetic Variation.—If the date of the original survey is known, the amount of variation may be determined from published tables giving the yearly variation for different sections of the country, but the date of the survey is often omitted. The date of the deed *must not* be taken as the date of the survey.

If one of the original boundaries remains unchanged, the magnetic variation can be determined at once by taking the present bearing of the line. The difference between the present bearing and that of the original survey is the required correction. The corrections are then to be made in the original bearings and the resulting courses run out. Where the measurements fall short of or overrun the original measurements, corrections must be made, locating the original corners if they can be found or establishing new ones, and, if possible, to the mutual satisfaction of adjoining proprietors.

1323. Establishing New Boundaries.—Where the description and map show a boundary to be a straight line and the actual boundary is found to be crooked, it is a good policy to establish a new and straight boundary by the principle of "give and take," providing adjoining owners will agree to the adjustment.

Fig. 314 illustrates the principle which is frequently employed in correcting such boundaries.

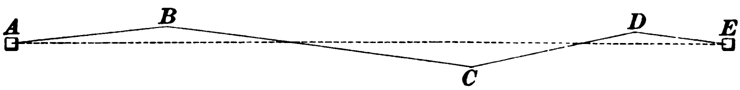


FIG. 314.

Let A and E be two corners and let the boundary line joining them be described and shown in the map as a straight

line. Let the irregular line $A\ B\ C\ D\ E$ represent the actual boundary. It is evident that the dotted straight line $A\ E$ may be substituted for the irregular line $A\ B\ C\ D\ E$, and would equitably divide the adjoining properties. The principle of give and take is applied, the adjoining owners making exchanges of equal areas.

The location of the new boundary is determined by making a careful survey of the old boundary and platting it to a large scale; a fine thread is then stretched on the plat and a line of division made as closely as may be estimated by the eye. The areas of the equalizing triangles are then calculated by scaling their dimensions, and if they do not balance the dividing line can readily be shifted until the desired result is obtained. The line is then measured on the ground and permanent corners established. Where the boundary is in woodland, careful search must be made for line and bearing trees. Blaze marks are very enduring, being easily recognized on some varieties of trees after a lapse of a quarter of a century.

1324. Lost and Obliterated Corners.—Corner monuments of perishable material, such as wooden posts, decay and in time become obliterated. A pile of stones, which is commonly used as a corner, may become scattered, and, unless permanent witnesses remain, it may be a difficult matter to restore the landmark. The most enduring witnesses are live trees which are disposed as shown in Fig. 315.

Three trees facing the corner are chosen ; in each tree three notches are cut in the side facing the corner, and the bearing and distance from each to the corner are recorded in the notes. A sketch is made in the note book giving the relative positions of the corner and the witness trees. When the corner is lost, but the witness trees still remain, the corner is restored by describing intersecting arcs from the witness trees as centers with radii equal to the given distances from the original corner. Where both corner and witnesses are gone, it is best to run from both directions towards the missing corner, placing the corner at the intersection of the

lines. The surveyor need not expect to find his measurements agree with those in original surveys, but he can save his successor much annoyance and trouble by careful and accurate work. He should always give both in map and in description the exact date of the survey; the direction of

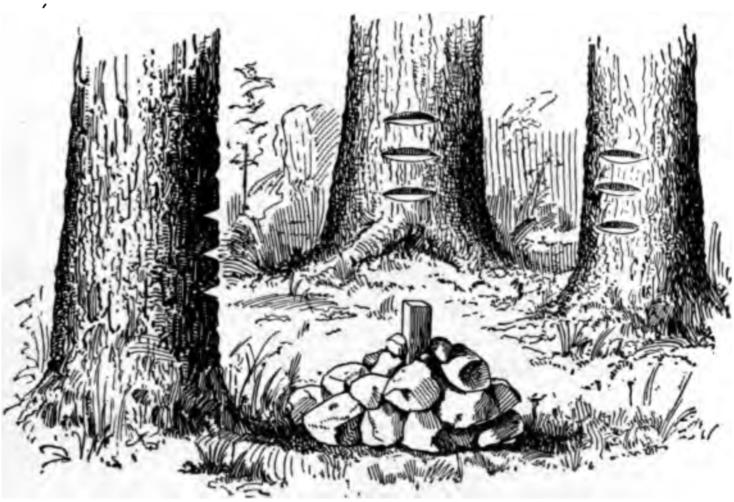


FIG. 315.

courses should also be given both in writing and figures, and the corners should be fully described. A stone monument is the best corner, and should always be used where the material is available.

AREAS.

1325. The **area** of a surface is its superficial content. In the surveying of public lands all measurements are made with the surveyor's chain, commonly known as Gunter's chain, from the name of the inventor. It is 66 feet in length and contains 100 links, each 7.92 inches long. At each interval of ten links a brass tag is attached with tally points similar to those on the engineer's chain described in Art. **1214.** Tables of surveyor's linear and square measure are given in Arts. **209** and **211.** For land areas the unit of measurement is the square foot = 144 square inches, though

areas of considerable extent are usually expressed in acres. An acre contains 43,560 square feet of surface. Rectangular areas are determined by multiplying the length in feet by the breadth in feet, and dividing the product by 43,560, which gives the area in acres.

In surveys of farms or larger tracts, dimensions are given in chains and links. The product of such dimensions is in square chains, which, divided by 10 (the number of square chains in an acre), gives the area in acres.

EXAMPLE.—A rectangular piece of land is 1,060 feet in length by 820 feet in breadth; required, the area.

SOLUTION.— $1,060 \times 820 = 869,200$ sq. ft. $869,200 \div 43,560 = 19.954$ acres. Ans.

DIFFERENT METHODS OF COMPUTING AREAS.

1326. By Dividing the Plat into Triangles.—Farms, especially in the older States of the Union, are commonly of irregular form. The readiest and—where the measurements have been accurately made—a sufficiently accurate method of determining areas is as follows: Make an accurate plat of the tract to as large a scale as may be conveniently used. Divide the resulting figure, an irregular polygon, into triangles, making their sides of as nearly equal length as possible. It is evident that the sum of the areas of the several triangles into which the polygon is divided is equivalent to the area of the polygon. This mode of calculating area is illustrated in Fig. 316.

Let the irregular polygon $A\ B\ C\ D\ E\ F$ be the outline of a tract of land the area of which is required. Draw the diagonals $B\ F$, $C\ F$, and $C\ E$, dividing the figure into four triangles, the combined area of which is equal to the area of the polygon. From the vertexes A, B, D, and E drop the perpendiculars $A\ G$, $B\ H$, $D\ K$, and $E\ L$ upon the opposite bases of the triangles. The lengths of the several bases and altitudes are measured with the scale and the areas of the several triangles calculated by the rule: *the area of a triangle is equal to one-half the product of its base and altitude.*

The sum of the areas of the several triangles is equal to the area of the polygon.

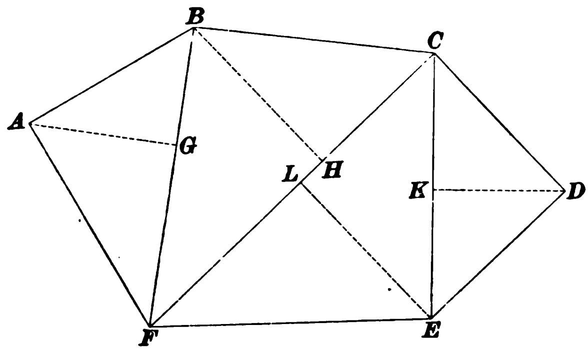


FIG. 316.

1327. By Dividing the Plat into Trapezoids.—A plat of the area having been made, it may be resolved into

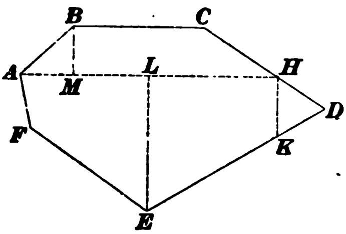


FIG. 317.

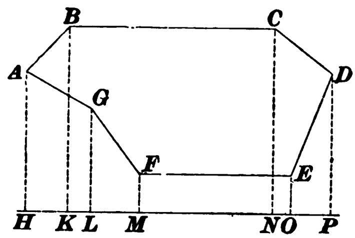


FIG. 318.

trapezoids by either of the methods shown in Figs. 317 and 318. In Fig. 317 the line $A\ H$ is drawn parallel to $B\ C$, and the lines $B\ M$, $K\ H$, and $E\ L$ are drawn perpendicular to $A\ H$, dividing the figure into trapezoids and the triangle $H\ D\ K$. The area of each trapezoid is equal to one-half the sum of its bases multiplied by its altitude, and the sum of their areas together with the area of the triangle is equivalent to the area of the polygon $A\ B\ C\ D\ E\ F$. In Fig. 318 a base line $H\ P$ is drawn, and from each angle of the polygon perpendiculars are drawn to it. The sum of the areas of the three trapezoids $A\ B\ K\ H$, $B\ C\ N\ K$, $C\ D\ P\ N$ is found, and

from that sum, the sum of the areas of the trapezoids *A G L H*, *G F M L*, *F E O M*, and *E D P O* is subtracted. The difference of these sums is the area of the polygon *A B C D E F G.*

LATITUDES AND DEPARTURES.

1328. Definitions.—The **latitude** of a point is its distance north or south of some "*parallel of latitude*" or line running *east* and *west*. The **longitude** of a point is its distance east or west of some *meridian* or line running *north* and *south.*

The meridian from which the longitude of a point is reckoned is the *magnetic meridian.*

The distance which one end of a line is due north or south of the other end is called the **latitude** of that line.

The distance which one end of a line is due east or west of the other end is called the **departure** of that line.

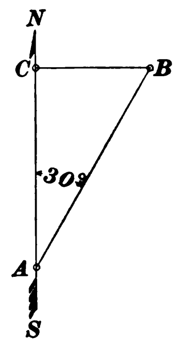


FIG. 319.

The latitude and departure of a line and its determination are explained in Fig. 319. Let *A B* be the given line whose length and angle with the magnetic meridian *N S* is known, and whose latitude and departure are required. From *B* draw *B C* perpendicular to *N S*, forming the right-angled triangle *A C B*, in which the sides *C A* and *C B* about the right angle are, respectively, the latitude and the departure of the line *A B*. Then,

$$A\ C = A\ B \times \cos \text{ bearing, and}$$
$$B\ C = A\ B \times \sin \text{ bearing;}$$

that is, the latitude is equal to the product of the cosine of the bearing and the length of the course; and the departure is equal to the product of the sine of the bearing and the length of the course.

Let $A\ B = 400$ feet and the bearing of *A B*, i. e., the angle $B\ A\ C = 30°$. Then, latitude $A\ C = \cos 30° \times 400 =$

$.86603 \times 400 = 346.412$ ft., and departure $B\ C = \sin 30° \times 400 = .50000 \times 400 = 200$ ft.

If the course be northerly, the latitude will be north, marked +, and be additive; if southerly, it will be marked −, and be subtractive. If the course be easterly the departure will be east, marked +, and be additive; if westerly, the departure will be west, marked −, and be subtractive.

1329. Traverse Tables.—The latitude and departure of any distance for any bearing can be found by a table of natural sines and cosines, but for facilitating work special tables, called traverse tables, have been prepared. They usually give the latitude and departure for any bearing to each quarter of a degree and for distances from 1 to 9.

To *use* the tables (see traverse tables, or Latitudes and Departures of Courses), find the number of degrees in the bearing in the left-hand column if the bearing be less than 45°, and in the right-hand column if the bearing be greater than 45°. The numbers on the same line running across the page are the latitudes and departures for that bearing and for the respective distances, 1, 2, 3, 4, 5, 6, 7, 8, 9, which appear at the top and bottom of the pages, and which may be taken to represent links, rods, feet, chains, or any other unit. Thus, if the bearing be 10° and the distance 4, the latitude will be 3.939 and the departure .695; with the same bearing, and the distance 8, the latitude will be 7.878 and the departure 1.389, or double the latitude and departure for the distance 4. Any distance, however great, can have its latitude and departure readily obtained from this table, since, for the same bearing, the latitude and departure are directly proportional to the distance because of the similar triangles which they form. Hence, the latitude and departure for 80 is ten times the latitude and departure for 8, and is found by moving the decimal point one place to the right; that for 500 is 100 times the latitude and departure for 5, and is found by moving the decimal

.point two places to the right, and so on. By moving the decimal point one, two, or more places to the right the latitude and departure may be found for any multiple of any number given in the table. In finding the latitude and departure for any number such as 453, the number is resolved into three numbers, viz.:

400	and the latitude and departure
50	for each taken from the table
3	and then added together.
453	

We thus obtain the following

Rule.—*Write down the latitude and departure, neglecting the decimal points, for the first figure of the given distance; write under them the latitude and departure for the second figure, setting them one place further to the right; under these place the latitude and departure for the third figure, setting them one place still further to the right, and so continue until all the figures of the given distance have been used; add these latitudes and departures and point off on the right of their sums a number of decimal places equal to the number of decimal places to which the tables being used are carried; the resulting numbers will be the latitude and departure of the given distance in feet, links, chains, or whatever unit of measurement is adopted.*

EXAMPLE.—A bearing is 16° and the distance 725; what is the latitude and departure?

Distances.	Latitudes.	Departures.
700	6729	1929
20	1923	0551
5	4806	1378
725	696.936	199.788

SOLUTION.—Taking the nearest whole numbers and rejecting the decimals, we find the latitude and departure to be 697 and 200.

When a 0 occurs in the given number the next figure must be set *two* places to the right, as in the following example:

EXAMPLE.—The bearing is 22° and the distance 907 feet; required, the latitude and departure.

SOLUTION.—

Distances.	Latitudes.	Departures.
900	8345	3371
7	6490	2622
907	840.990	339.722

Here the place of 0 in both the distance column and in the latitude and departure columns is occupied by a dash —. Rejecting the decimals, the latitude is 841 feet and the departure 340 feet. When the bearing is more than 45°, the names of the columns must be read from the bottom of the page. The latitude of any bearing, as 60°, is the departure of its complement, 30°; and the departure of any bearing, as 30°, is the latitude of its complement, 60°. This will be readily understood from an inspection of Fig. 320, in which if NS be the magnetic meridian and $BOA = 60°$ the bearing, then AO is the latitude and AB the departure. If, now, OC be made the meridian and $BOC = 30°$ (the complement of BOA) the bearing, then OC (the equal of AB) is the latitude, and BC (the equal of AO) the departure.

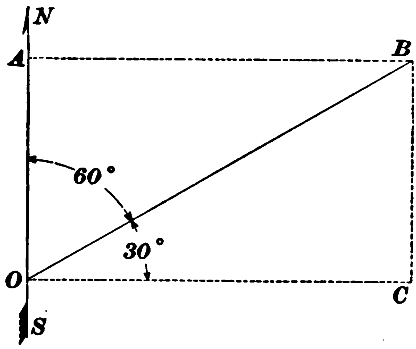


FIG. 320.

EXAMPLE.—Let $OB = 1{,}326$ feet, and its bearing $= 60°$.

SOLUTION.—

Distances.	Latitudes.	Departures.
1,000	0500	0866
300	1500	2598
20	1000	1732
6	3000	5196
1326	663.000	1148.316

The required latitude is 663 feet and the departure 1,148 feet.

Where the bearings are given in smaller fractions of degrees than is found in the table, the latitudes and departures can be found by interpolation.

Traverse tables are chiefly employed in testing the accuracy of surveys, platting them, and calculating their content.

1330. Testing a Survey.—When a surveyor has completed the survey of a field or farm by taking bearings

and measuring courses, it is evident that he has gone as far north as south and as far east as west. The sum of the north latitudes shows how far north he has gone, and the sum of the south latitudes shows how far south he has gone. The sum of the east departures shows how far east he has gone, and the sum of the west departures shows how far west he has gone. Hence, if the survey has been correctly made these sums will be equal or will balance.

The entire operation of testing a survey is illustrated in the following example:

Stations.	Bearings.	Distances.	Latitudes.		Departures.	
			N +	S −	E +	W −
1	N 34¼° E	273	226		154	
2	N 85½° E	128	10		128	
3	S 56¾° E	220		121	184	
4	S 34¼° W	353		292		199
5	N 56½° W	320	177			267
			413	413	466	466

34¼°	1653	1126	85½°	0078	0997
273	5786	3940	128	0157	1994
	2480	1688		0628	7975
	225.640	153.688		9.998	127.615
56¾°	1097	1673	34¼°	2480	1688
220	1097	1673	353	4133	2814
	120.67	184.03		2480	1688
				291.810	198.628

56½°	1656	2502
320	1104	1668
	176.64	266.88

Adding up the north and south latitudes we find them to exactly balance each other, as do the east and west departures, which proves the survey to be correct. On account of the inherent defects of the compass and the errors which are

liable to occur in measurement, especially on rough and extensive areas, it is but rarely that the survey will exactly balance. A moderate discrepancy, which would indicate what may be called unavoidable errors, will be allowable, and the survey accepted as correct. How great a difference in the sums of the columns may be allowed is a doubtful question. Every surveyor of experience knows the average degree of accuracy of his work, and will readily distinguish between a serious error and an allowable inaccuracy.

1331. Balancing a Survey.—When the sums of the latitudes and of the departures do not equal each other, and yet the difference does not indicate any error, the different latitudes and departures are modified so that their sums shall be equal. This process is called *balancing the survey.*

The error is distributed among the different courses in proportion to their length by the following

Rule.—*As the sum of all the courses is to any separate course, so is the whole difference in latitude to the correction for that course. A similar proportion corrects the departures.*

An example illustrating the process of balancing a survey is given below. In this example four separate columns are given for the corrected latitudes and departures. In practice, however, the corrected latitudes and departures are written in red ink directly above the original ones, which are crossed out with red ink. The distances given are in chains:

Stations.	Bearings.	Distances.	Latitudes.		Departures.		Corrected Latitudes.		Corrected Departures.	
			N +	S −	E +	W −	N +	S −	E +	W −
1	N 52° E	10.63	6.55		8.38		6.58		8.34	
2	S $29\frac{3}{4}$° E	4.10		3.56	2.03			3.55	2.01	
3	S $31\frac{3}{4}$° W	7.69		6.54		4.05		6.51		4.08
4	N 61° W	7.13	3.46			6.24	3.48			6.27
		29.55	10.01	10.10	10.41	10.29	10.06	10.06	10.35	10.35

The corrections are made by the following proportions:

For Latitudes.	For Departures.
29.55 : 10.63 :: 9 : 3 links.	29.55 : 10.63 :: 12 : 4 links.
29.55 : 4.10 :: 9 : 1 link.	29.55 : 4.10 :: 12 : 2 links.
29.55 : 7.69 :: 9 : 3 links.	29.55 : 7.69 :: 12 : 3 links.
29.55 : 7.13 :: 9 : 2 links.	29.55 : 7.13 :: 12 : 3 links.
9	12

This rule should not always be strictly followed, especially if one line has been measured over rough and broken country, while the others have been measured over smooth and open ground. In such a case the greater part of the error will probably lie in the rough line, and, consequently, it should receive the larger share of the correction. A slight alteration of a bearing will sometimes balance a survey. This may be done where an obstructed sight has probably caused an error in the bearing.

1332. Application of Latitudes and Departures to Platting.—Rule three columns, one for stations, the next for total latitudes, and the third for total departures, as shown in the following diagram.

To obtain the total latitudes, begin at any station, the extreme east or west one is preferable, and add up algebraically the latitudes of the following stations, observing that north latitudes are plus (+), and south latitudes minus (−). In the same manner find the algebraic sum of the departures for the different stations, placing each successive sum opposite its proper station.

In the example given in Art. **1330,** beginning at Station *1*, we obtain the following results.

Stations.	Total Latitudes from Station 1.	Total Departures from Station 1.
1	0.00	0.00
2	+ 2.26	+ 1.54
3	+ 2.36	+ 2.82
4	+ 1.15	+ 4.66
5	− 1.77	+ 2.67
1	0.00	0.00

The work is proved to be correct by the latitudes and departures for Station *1* coming out equal to 0. To apply these total latitudes and departures in platting,

we draw a meridian through the point taken as Station *1*, Fig. 321. Scale off from Station *1* upwards on this meridian the latitude 2.26 chains to *A* and to the right from *A*, and perpendicularly lay off the departure 1.54 chains to Station *2*. Join *1-2*. From *1* again lay off the latitude 2.36 (= 2.26 + 10) chains to *B*, and to the right perpendicularly the departure 2.82 (= 1.54 + 1.28) chains to Station *3*. Join *2-3*, and proceed in like manner to locate Stations

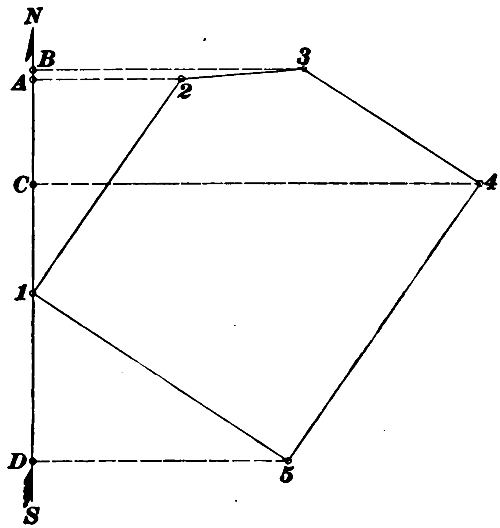


FIG. 321.

4 and *5*, laying off + latitudes above Station *1* and + departures to the right of the meridian, and − latitudes below Station *1* and − departures to the left of the meridian. The principal advantages of this mode of platting are rapidity of work, the fact that each course is platted independently, and the certainty of the plats closing, provided the latitudes and departures have previously been balanced.

1333. Calculating the Content.—The survey of a field or farm having been made and platted, the content can always be found by dividing the plat into triangles, and

scaling off their bases and perpendiculars from which the contents are calculated. This and other methods previously mentioned are only approximate, the degree of accuracy depending upon the largeness of the scale and the skill of the draftsman. The method of calculating content by latitudes and departures is perfectly accurate, and does not require the previous preparation of a plat.

1334. Definitions.—If a meridian be passed through the extreme east or west corner of a field, the perpendicular distance from any station to that meridian is the *longitude* of that station, additive or plus if east and subtractive or

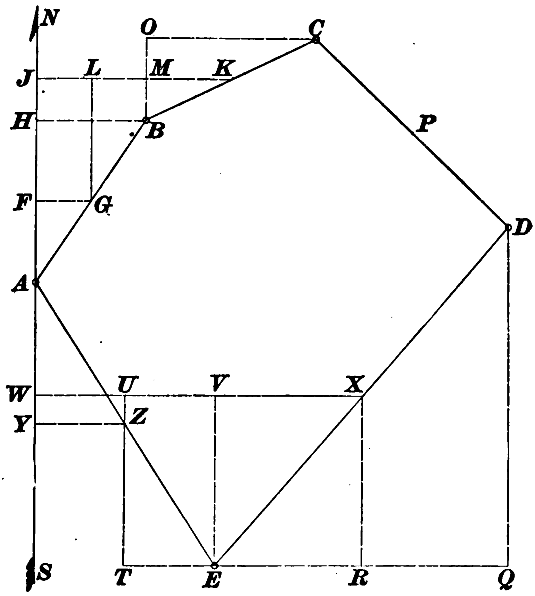


FIG. 322.

minus if west. The distance of the middle point of any line, such as the side of the field, from the meridian is called the **longitude** of that side. The difference of the longitudes of the two ends of a line is called the **departure** of the line; the difference of the latitudes of the two ends of a line is called the **latitude** of the line.

1335. Longitudes.—Let $N\ S$, Fig. 322, be the meridian passing through the extreme westerly station of the field $A\ B\ C\ D\ E$. From the middle and ends of each side draw perpendiculars to the meridian. These perpendiculars will be the longitudes and departures of the respective sides. The longitude $F\,G$ of the first course $A\ B$ is evidently equal to one-half its departure $H\,B$. The longitude $J\,K$ of the second course $B\ C$ is equal to $J\,L + L\,M + M\,K$ equal to the longitude of the first course plus half the departure of the first course plus half the departure of the course itself. The longitude $Y\,Z$ of some other course $E\ A$, taken anywhere, is equal to $W\,X - V\,X - U\,V$, or equal to the longitude of the preceding course minus half the departure of that course minus half the departure of the course itself, i. e., equal to the *algebraic* sum of these three parts, remembering that south latitudes and west longitudes are negative, and, therefore, to be subtracted when the instructions are to make an algebraic addition.

To avoid fractions, the preceding expressions are doubled, whence we deduce the following

Rule for Double Longitudes:

The double longitude of the first course is equal to its departure.

The double longitude of the second course is equal to the double longitude of the first course plus the departure of that course plus the departure of the second course.

The double longitude of the third course is equal to the double longitude of the second course plus the departure of that course plus the departure of the course itself.

The double longitude of any course is equal to the double longitude of the preceding course plus the departure of that course plus the departure of the course itself.

The double longitude of the last course (as well as of the first) is equal to its departure. This result, when obtained by the above rule, proves the accuracy of the calculation of the double longitudes of all the preceding courses.

1336. Areas.—The following is an application of the rule for finding areas by *double longitudes*. See Fig. 323. Let $A\ B\ C$ be a *three-sided field*, of which A is the most westerly station. Through A draw a meridian, and from the stations B and C and the middle points of the three sides of the field draw perpendiculars to the meridian. It is evident that the area of the field $A\ B\ C$ is equal to the area of the trapezoid $D\ B\ C\ E$ less the triangles $A\ D\ B$ and $A\ E\ C$. The area of the triangle $A\ D\ B$ is equal to the product of $A\ D$ by $F\ G$, i. e., it is equal to the product of the latitude of the first course by its longitude. The area of the trapezoid $D\ B\ C\ E$ is equal to the product of $D\ E$ by half the sum of $D\ B$ and $E\ C$, or $H\ K$, i. e., it is equal to the product of the latitude of the second course by its longitude. The area of the triangle $A\ E\ C$ is equal to the product of $A\ E$ by half $E\ C$, or $L\ M$, i. e., it is equal to the product of the latitude of the third course by its longitude. The bearing of the course $A\ B$ is N E, and that of $C\ A$ is N W. Their latitudes are, therefore, *north*. The bearing of the course $B\ C$ is S E, and its latitude is *south*. Calling the products in which the latitude is north, *north products*, and the products in which the latitude is south, *south products*, we find the area of the trapezoid to be a south product and the areas of the triangles to be north products. The difference of the north products and the south products is, therefore, the area of the three-sided field $A\ B\ C$.

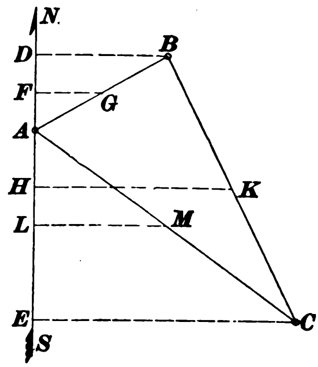


FIG. 323.

Using *double* longitudes, to avoid fractions, in each of the preceding products, their difference will be *double* the area of the field $A\ B\ C$.

Take, now, a four-sided field, $A\ B\ C\ D$, Fig. 324, and drawing a meridian through its most westerly station A,

and longitudes as in the preceding case, it will be evident from inspection that the area of the field *A B C D* is equal to the trapezoid *F C D G*, diminished by the area of triangles *A G D*, *A E B*, and the trapezoid *E B C F*. The area of the triangle *A E B* is equal to the product of the latitude *A E* of the first course by its longitude *H K*. Its product is *north*. The area of the trapezoid *E B C F* is equal to the product of the latitude *E F* of the second course by its longitude *L M*, and is also a *north* product. The area of the trapezoid *F C D G* is equal to the product of the latitude *F G* of the third course by its longitude *N O*, a *south* product. The area of the triangle *A G D* is equal to the product of the latitude *A G* of the fourth course by its longitude *P Q*, a north product. Subtracting the sum of the north products from the sum of the south products the difference is the area of the field *A B C D*. If *double* longitudes had been used, as in the previous case, the difference would have been *double* the area of the field.

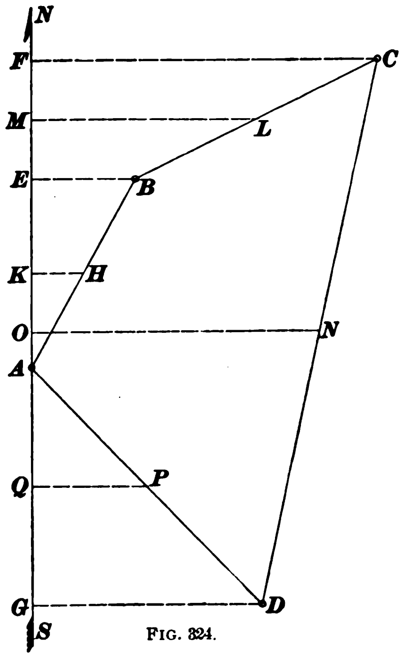


FIG. 324.

1337. The Application of Double Longitudes to the Finding of Areas.—Whatever the number or directions of the sides of a field or any surface enclosed by straight lines, its area will always be equal to *half* the difference of the north and south products arising from multiplying together the latitude and *double* longitude of each course or side, whence the following

General Rule for Finding Areas:

1. Prepare ten columns, headed as in the following examples, and in the first three write the stations, bearings, and distances.

*2. Find the latitudes and departures of each course by the traverse table, as directed in Art. **1329**, placing them in the four following columns.*

*3. Balance them as in Art. **1331**, correcting them in red ink.*

*4. Find the double longitudes as in Art. **1335**, with reference to a meridian passing through the extreme east or west station, and place them in the eighth column.*

5. Multiply the double longitude of each course by the corrected latitude of that course, placing the north products in the ninth column and the south products in the tenth column.

6. Add the last two columns; subtract the smaller sum from the larger, and divide the difference by two. The quotient will be the content required.

1338. To Find the Most Easterly or Westerly Station of a Survey.—Make a rough hand sketch of the tract, giving the sides, their approximately true direction, and length. The most easterly or westerly station may then be determined from an inspection of the sketch.

Example 1 of this article refers to the five-sided field, a plat of which is given in Fig. 321, and the latitudes and departures of which were calculated in Art. **1330.** Station *1* is the most westerly in the plat, and the meridian will be passed through it.

The double longitudes are found by applying the rule for double longitudes, given in Art. **1335.** As the additions are made algebraically, due attention must be paid to the signs. The double longitudes are marked D. L., as shown in the marginal diagram. These double longitudes are obtained by the following operation. As stated in the rule, the double longitude of the first course is equal to the

departure. By reference to the given example, we find that the departure of the first course is 1.54 chains, an *cast* departure, and, therefore, positive. We record this in the column headed D. L., opposite Station *1*. The D. L. of the second course is equal to the D. L. of the first course plus the departure of that course plus the departure of the second course. Accordingly, we place under the D. L. of the first course, the departure of that course, viz., + 1.54, and the departure of the second course, viz., + 1.28, as given in the east departure column of the example. This sum, viz., + 4.36 is the D. L. of the second course and placed opposite Station *2*. The D. L. of the third course is equal to the D. L. of the second course plus the departure of that course plus the departure of the third course. Accordingly, we place under the D. L. of the second course the departure of that course, viz., + 1.28, and the departure of the third course, viz., + 1.84. This sum, + 7.48, is the D. L. of the third course, which we place opposite Station *3*. In a similar manner we find the D. L. for the fourth and fifth courses. The double longitude of the last course is equal to its departure, which proves the work. The double longitudes of the courses are then multiplied by their corresponding latitudes, and the content of the field obtained as directed in the given rule.

Stations.	D. L.
1	+ 1.54 D.L.
	+ 1.54
	+ 1.28
2	+ 4.36 D.L.
	+ 1.28
	+ 1.84
3	+ 7.48 D.L.
	+ 1.84
	− 1.99
4	+ 7.33 D.L.
	− 1.99
	− 2.67
5	+ 2.67 D.L.

Had the meridian been supposed to pass through Station *4*, the most easterly station, all the longitudes would have been west or minus, but the difference in the double areas would have been the same, giving the same content as before.

The following examples will give the student some practice in the use of traverse tables, and in applying latitudes and departures in the calculation of areas:

EXAMPLE 1.

Stations.	Bearings.	Distances. Chains	Latitudes.		Departures		Double Longitudes.	Double Areas.	
			N +	S −	E +	W −		N +	S −
1	N 34¼° E	2.73	2.26		1.54		+ 1.54	3.4804	
2	N 85½° E	1.28	.10		1.28		+ 4.36	.4360	
3	S 56¾° E	2.20		1.21	1.84		+ 7.48		9.0508
4	S 34¼° W	3.53		2.92		1.99	+ 7.33		21.4036
5	N 56½° W	3.20	1.77			2.67	+ 2.67	4.7259	
		12.94	4.13	4.13	4.66	4.66		8.6423	30.4544
									8.6423
									2)21.8121
								Square chains,	10.9061

Content = 1 A. 0 R. 14.50 P.

EXAMPLE 2.

Stations.	Bearings.	Distances. Chains.	Latitudes.		Departures.		Double Longitudes.	Double Areas.		Stations.	D. L.
			N +	S −	E +	W −		N +	S −		
			6.56		8.37						
1	N 52° E	10.64	~~6.53~~		~~8.38~~		+ 8.37	54.9072		1	+ 8.37 D. L.
2	S 29¾° E	4.09		3.55	2.02		+ 18.76		66.5980		+ 8.37
				6.52							+ 2.02
3	S 31¾° W	7.68		~~6.53~~		4.05	+ 16.73		109.0796	2	+ 18.76 D. L.
						6.34					+ 2.02
4	N 61° W	7.24	3.51			~~6.33~~	+ 6.34	22.2534			− 4.05
		29.65	10.06	10.08	10.41	10.37		77.1606	175.6776	3	+ 16.73 D. L.
			10.07	10.07	10.39	10.39			77.1606		− 4.05
									2) 98.5170		− 6.34
								Square chains,	49.2585	4	+ 6.34 D. L.

Content = 4 A. 3 R. 28.14 P.

EXAMPLE 3.

Stations.	Bearings.	Distances. Chains.	Latitudes. N +	Latitudes. S −	Departures. E +	Departures. W −	Double Longitudes.	Double Areas. N +	Double Areas. S −
				3.13	4.85				
1	S 57° E	5.77		3.14	4.84		− 4.85		15.1805
2	S 36¼° W	2.25		1.81		1.33	− 1.33		2.4073
3	S 39¼° W	1.00		.77		.63	− 3.29		2.5333
4	S 70¼° W	1.04		.35		.98	− 4.90		1.7150
5	N 68¾° W	1.23	.45			1.15	− 7.03	3.1635	
6	N 56° W	2.19	1.22			1.82	− 10.00	12.2000	
7	N 33¼° E	1.05	.88		.58		− 11.24	9.8912	
8	N 56½° W	1.54	.85			1.28	− 11.94	10.1490	
			2.66						
9	N 33½° E.	3.18	2.65		1.76		− 11.46	30.4836	
		19.25	6.05	6.07	7.18	7.19		65.8873	21.8361
			6.06	6.06	7.19	7.19		21.8361	
								2) 44.0512	
Content = 2 A. 0 R. 32.4 P.							Square chains,	22.0256	

Stations.	D. L.
2	− 1.33 D. L.
	− 1.33
	− .63
3	− 3.29 D. L.
	− .63
	− .98
4	− 4.90 D. L.
	− .98
	− 1.15
5	− 7.03 D. L.
	− 1.15
	− 1.82
6	− 10.00 D. L.
	− 1.82
	+ .58
7	− 11.24 D. L.
	+ .58
	− 1.28
8	− 11.94 D. L.
	− 1.28
	+ 1.76
9	− 11.46 D. L.
	+ 1.76
	+ 4.85
1	− 4.85 D. L.

The notes of the survey given in Example 3 are platted by total latitudes and totai departures from Station *1*. A plat of the survey is given in Fig. 325 and the total latitudes and departures in the accompanying table. From an inspection of the plat it will be seen that Station *2* is the most easterly, and the double longitudes given in Example 3 are reckoned from a meridian passing through that station.

Stations.	Total Latitudes from Station 1.	Total Departures from Station 1.
1	0.00	0.00
2	− 3.13	+ 4.85
3	− 4.94	+ 3.52
4	− 5.71	+ 2.89
5	− 6.06	+ 1.91
6	− 5.61	+ .76
7	− 4.39	− 1.06
8	− 3.51	− .48
9	− 2.66	− 1.76
1	− 0.00	0.00

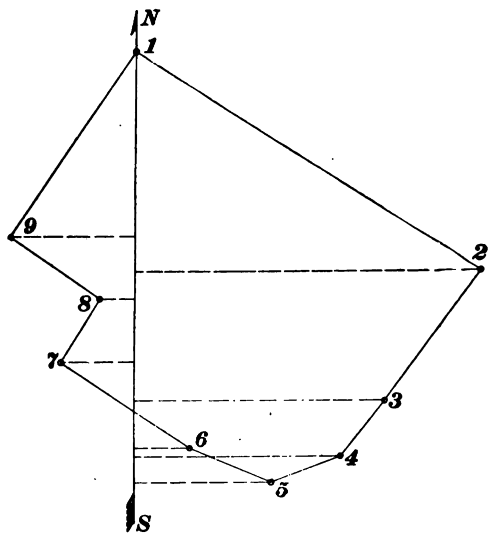


FIG. 325.

TOWN SITES AND SUBDIVISIONS.

1339. First Considerations.—In laying out town sites the consideration of first importance is the location of the streets rather than the greatest number of lots obtainable. The custom of laying out town sites in rectangular lines,

without reference to topographical conditions, prevails almost universally throughout the United States. This is largely owing to two principal causes, viz., first, the supposition that the rectangular method or plan will yield the greater number of lots, and, hence, the greater profit, and, second, the haste in surveying, platting, and placing the property on the market does not admit of a thorough study of the ground.

The town site should be considered as a whole, the location of its main streets and thoroughfares being determined by traffic considerations chiefly. These considerations will necessarily involve the questions of grades, drainage, and railway communications. Without the latter there is small excuse for a town. Where possible a main avenue should be laid out, parallel with the railroad, leaving one tier of lots between the street and track. This avenue may then be used as a base from which to lay out the adjoining streets and avenues, which may be parallel with and at right angles to it if the surface be generally level, or at oblique angles if the surface be rolling or hilly.

1340. Grades, Drainage, and Topography.—Grades and drainage should be so arranged that surface water will tend to form main channels, i. e., the surface water of several streets will find its way into some particular street where special provision can be made for its control and discharge.

The streets in the residential portion of the town should, so far as possible, conform to the existing topographical conditions. This will greatly reduce the cost of grading the streets, give easy grades, and so promote comfort of pedestrians and the efficiency of teams. There is no loss in frontage from the employment of curves instead of straight lines, and there is no question of the advantage of the former from an artistic standpoint.

The accompanying plan, Fig. 326, is made to meet the following conditions, viz., two lines of railroad, a main line and branch, meet at the junction of two streams. The land

bordering on the smaller stream, which is followed by the branch road, rises rapidly from the stream, reaching a height of 200 feet, and then falls gradually until an elevation of 50 feet above the stream is reached, when the surface remains generally level. The land bordering the larger stream, which is followed by the main line of the railroad, rises gradually until a height of 50 feet above the stream is reached, beyond which the surface is generally level.

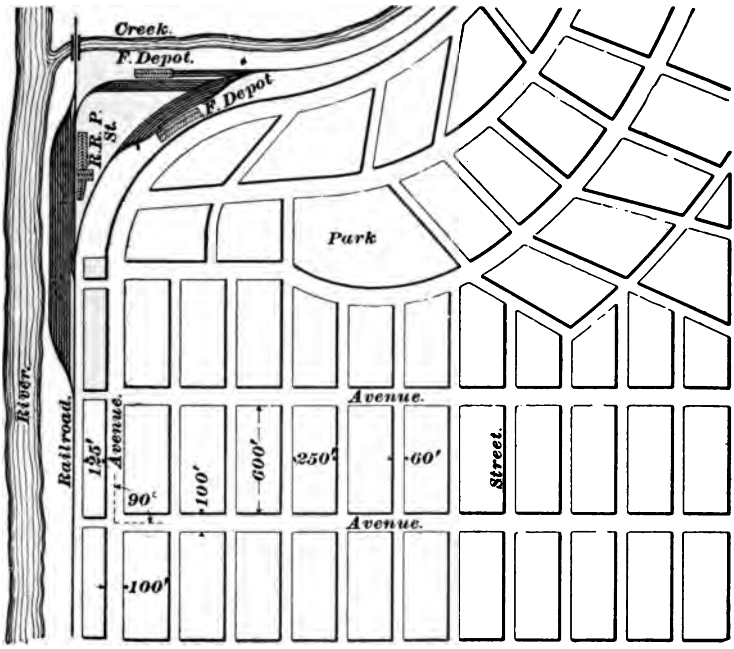


FIG. 326.

That part of the given surface which is generally level will be laid out in rectangular blocks. The unaided eye will readily determine whether a town site is well adapted to rectangular divisions. If it is so adapted the order of survey will be as follows:

1341. General Directions for Preliminary Survey.—Run a line enclosing the entire area, giving location of prominent features, such as railroads, highways, streams,

houses, etc., and accurately plat to a scale of 200 feet to the inch. For cities, avenues are made 100 feet in width between building lines, and streets 60 feet, the avenues being parallel to each other and the streets at right angles to the avenues. City lots usually have fronts of 25 feet and depths of 125 feet. Part of New York is laid out in blocks of 200 feet by 800 feet, the 200 feet facing the avenues. Lots are 100 feet in depth, each block containing 64 lots. Having determined the dimensions of the streets and blocks, lay out the principal base line so that it will form the center line of a street or avenue running parallel with the general direction of the railroad, providing for overhead or sub-crossings where practicable. If crossings must be at grade, the fewer of them the better. Provide easy and safe access to railroad stations and freight depots.

Lay out the plat in rectangular blocks, accurately scaling all dimensions. Arrange the plan so as to interfere as little as possible with existing lines of travel, at the same time giving due regard to the future needs of an increasing population. If the ground is wooded or sight obstructed by underbrush, but one additional base line can be used. It should be about midway between the extremities of the principal base line and at right angles to it. If, however, the ground is open with nothing to interfere with long sights, two base lines should be laid out, one at either extremity of the main base and at right angles to it.

1342. Measurements.—All measurements should be made with a standard steel tape and plumb-bob and carefully checked. The base lines especially should be measured with great care, as the correctness of all the subsequent measurements depends upon the degree of accuracy with which these primary lines are measured.

1343. Base Lines and Subdivisions.—The rectangular method of surveying town sites is illustrated in Fig. 327, in which *A B* is the principal base, and the auxiliary bases *A D* and *B C* are laid off from the extremities of *A B*. The avenues are at right angles to *A B*, and the

streets parallel to $A\ B$. Avenue A is parallel to the railroad,

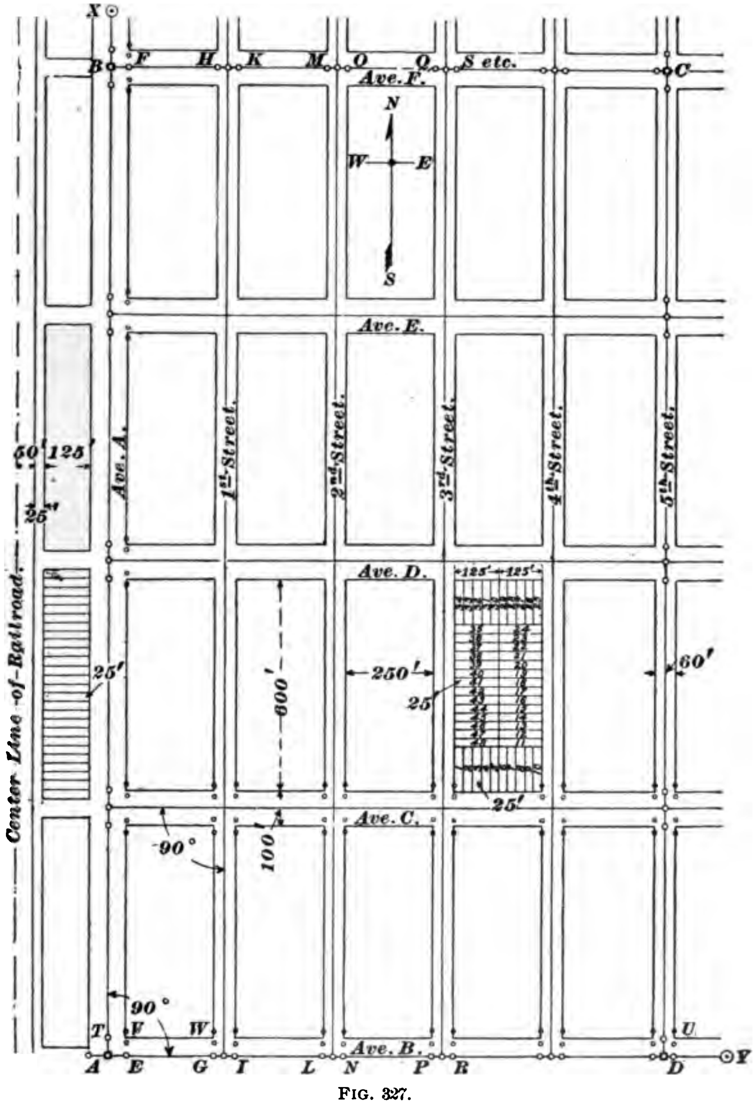


FIG. 327.

from which it is separated by a 25-foot alleyway and one tier of lots 125 feet deep. Avenues are 100 feet in width,

streets 60; blocks 250 feet by 600 feet, fronting 250 feet on the avenues, and the lots are 25 feet by 125 feet.

The initial point *A* of the principal base *A B* is the center of an avenue, and should be fixed by a plug 2″ × 2″ × 18″ driven flush with the surface of the ground and the center marked by a tack, with a guard stake beside it, and numbered 0. Drive a temporary plug at *X* to be used as a foresight in giving the direction of *A B*. Set up the instrument at *A* and sight to *X*, frequently checking the foresight. Measure from *A* on *A B* 50 feet, and drive a 12″ plug, carefully centering the same. This point marks the north side of Avenue *B*. Continue measuring on the line *A B*, driving a stake at each hundred feet, marking the exact measurement by a tack, and number in regular succession from *A*. At 650 feet from *A* set a 12″ plug with tack center, marking the south side of Avenue *C*; 50 feet further, at Station 7, set a 12″ plug with center. This point will be in the center of Avenue *C*; at 7 + 50 a plug with center is set, marking the north side of Avenue *C*. In like manner locate the center and sides of all avenues lying between *A* and *X*, always checking the foresight before setting tack centers. At *B* set a plug 2″ × 2″ × 18″. At each station remeasure the last 100 feet, so as to secure accurate results. The measurement of the main base line *A B* being completed, take a foresight on *X* and turn off an angle of 90°, setting a temporary plug at *Y*. Mark the center at *Y* with a pencil point and repeat the angle five times, marking a center at *Y* for each angular measurement. These points will vary slightly in position, though two of them may fall at the same place. Take the mean or average of these points, and mark the point with a tack. Then, commencing at *A* measure the line *A Y*, setting stakes at each 100 feet, as in *A B*, and set hubs on the side lines of Avenue *A* and at centers and side lines of the streets parallel to it, checking the foresight at *Y* and the measurement of each station before setting plug centers. On this line the measurements will be, first 50 feet, next 250, then 60, 250, 60, etc., the streets being 60 feet and the blocks 250 feet in width. At *D* set a plug

$2'' \times 2'' \times 18''$. In a similar manner locate the base line *B C* and the street centers and side lines on *B C*. Then set up at *D*, which is a permanent point, and foresighting to *C* set points on centers and sides of avenues on *D C*. Next set up at *E*, foresighting to *F*. Provide a supply of plugs $1'' \times 1'' \times 8''$ and measure from *E*, 50 feet in both directions on the line *E F*, and mark the points with pins. These points will be on the north and south lines of Avenue *B*. On either side of these pins in the line *E F*, and about two feet from them, set plugs, leaving two inches of their length above the surface of the ground. Center these plugs, driving tacks half their length into each one. In the same manner set plugs on both sides of each street line as indicated by the small circles in the figure. In this example *B C* is 2,800 feet distant from *A D*, too great a distance for the accurate setting of plug centers; therefore, the measurements from *A D* to *B C* should terminate on the south line of Avenue *D*. In the same manner locate plugs on the lines *G H*, *I K*, *L M*, etc. Having set all plugs between the base *A D* and the south line of Avenue *D*, move the instrument to *F* and, foresighting to *E*, set plugs on both sides of all avenues between Avenue *F* and Avenue *D*, including the north side of *D*. In like manner locate plugs on *H G*, *K I*, *M L*, etc. Move the instrument to the point *U*; stretch pieces of cord between the plugs on both sides of the line *X T*; foresight to *T*, and at each intersection with the cord, as at *V*, *W*, etc., drive a $12''$ plug, and center with a tack. This method of locating street corners by intersections has the advantage of bringing all corners on the same street in perfect line, a result which it would be practically impossible to obtain by direct measurement. The measurement of all angles is referred to the base lines where special care is taken in checking them.

1344. Permanent Monuments.—The street and avenue centers located on the base lines should always be rendered permanent by setting stone monuments at those points.

MAPPING.

INTRODUCTION.

1345. The object of this section is to furnish the student thorough, practical instruction in mapping. Having previously mastered the section on Geometrical Drawing, he should by this time be familiar with the various instruments employed in the drafting room, and be accustomed to their use.

All the principles and methods here described are fully illustrated by drawings, which comprise six plates, found at the end of the volume on Mechanical Drawing. These plates the student will be required to draw, and the degree of proficiency, as shown by his work, will determine his standing. The examples given in the plates are similar to those met with in practical field and office work.

1346. A **map** is a series of lines and angles so combined as to represent the true outlines, proportions, and character of any required surface.

1347. **Lines** are either boundaries or divisions of the required surface. They have only the properties of direction and length.

DRAWING THE PLATES.

PLATE, TITLE: PLATTING ANGLES I.

1348. This plate contains six angle lines, three of which are comprised by Fig. 1 and three by Fig. 2. The three lines *a*, *b*, and *c*, under Fig. 1, will be drawn to a scale of 200 feet to the inch, platting the angles with a protractor, the

use of which was fully explained in the section relating to Geometrical Drawing.

The student will plat these lines according to the following directions, being careful to give to each line approximately the same position it occupies in the plate. This statement also applies to all the plates which are to be drawn from the data given in this section. In these examples, distances are expressed in stations of 100 feet each, as in the section on Surveying. The direction of each line is referred to that of the immediately preceding line, which line is produced and the angle recorded as being to the right or left of that line. In practical office work, the lines produced are drawn lightly in pencil and erased as soon as the angles are laid off. In the lines *a* and *b*, Fig. 1, the lines produced are dotted and the angles written in dotted arcs, in order that the student may clearly and fully understand the method. The dimensions of the following plates and the directions for drawing the border lines are the same as for the plates on Geometrical Drawing. The notes for line *a* in Fig. 1 are as shown.

NOTES FOR LINE *a*.

Stations.	Angles.
25 + 84	End of Line.
21 + 94	L. 32° 35′
15 + 53	R. 44° 10′
11 + 72	L. 60° 30′
5 + 25	L. 25° 15′
0	

1349. The starting point A of the line is numbered 0. The first angle turned is at Sta. 5 + 25, which we denote by B. Locating the starting point A about three-fourths of an inch from the lower and left-hand border lines, we draw a straight line, giving it the same direction as that given to it in the engraving. Scale off from A, to a scale of 200 feet to the inch, the first course, 525 feet in length, locating the point B. Produce $A\ B$ to C, being sure to make $B\ C$ a little greater than the diameter of the protractor. At Sta. 5 + 25, B, an angle of 25° 15′ is turned to the left. Now,

placing the center of the protractor on the point B, with the zero point on the line $B\ C$, lay off the angle 25° 15′ to the left of $B\ C$, marking the point of angle measurement D with a needle point. Through the points B and D draw a straight line. The angle $C\ B\ D$ is 25° 15′, and the line $B\ D$ is the direction of the next course. The second angle, 60° 30′, is turned to the left at Sta. 11 + 72. The length of the second course is found by subtracting 525 from 1,172, giving a difference of 647 ft. Produce $B\ D$ and scale off the second course 647 ft., locating the point E at Sta. 11 + 72. Produce $B\ E$ to F, and lay off to the left of $E\ F$ the angle 60° 30′, locating the point G. Join E and G. The angle $F\ E\ G$ is 60° 30′, and the line $E\ G$ is the direction of the next course.

The third angle is R. 44° 10′, and is turned at Sta. 15 + 53. The length of the third course is found by subtracting 1,172 from 1,553, giving a difference of 381 feet. Produce $E\ G$ and scale off from E the distance 381 ft., locating the point H at Sta. 15 + 53. Produce $E\ H$ to K, and to the right of $H\ K$ lay off the given angle 44° 10′, locating the point L. The line joining the points H and L forms with $H\ K$ an angle of 44° 10′, and gives the direction of the next course. The next angle is L. 32° 35′, and is turned at Sta. 21 + 94. The length of the course is found by subtracting 1,553 from 2,194, giving a difference of 641 ft. Produce $H\ L$ and scale off from H the distance 641 ft., locating the point M at Sta. 21 + 94. Produce $H\ M$ to N, and to the left of $M\ N$ lay off the given angle 32° 35′, locating the point O. Draw $M\ O$. The angle $N\ M\ O$ is 32° 35′, and $M\ O$ is in the direction of the next and last course of line a, whose length is found by subtracting 2,194 from 2,584. The difference is 390 ft. We produce the line $M\ O$, and from M scale off the last course of 390 ft., locating the point P at Sta. 25 + 84. At each angular point in the line an arc is described, giving the measurement of the angle.

The student will in a similar manner plat the following notes for the lines b and c, Fig. 1, of the same plate:

NOTES FOR LINE *b*.

Stations.	Angles.
23 + 10	End of Line
16 + 35	R. 25° 10′
12 + 82	L. 15° 15′
8 + 50	L. 30° 40′
4 + 40	R. 15° 20′
0	

NOTES FOR LINE *c*.

Stations.	Angles.
28 + 60	End of Line
21 + 46	R. 34° 30′
17 + 09	R. 53° 28′
11 + 96	L. 25° 10′
5 + 33	R. 21° 10′
0	

1350. To Lay Off an Angle by Chords.—This is done by means of a table of chords in which the lengths of chords for all angles from 0 to 90° are given in terms of a radius 1. A radius of any convenient length may be assumed, and the corresponding chord length obtained by multiplying the length of the chord given in terms of radius 1 by the length of the assumed radius. Thus, let it be required to lay off from a given line an angle of 40° 10′ to the left. Let *A B*, Fig. 328, be the given line. Produce *A B* to *C*, making *B C* = 400 ft., the length of the assumed radius.

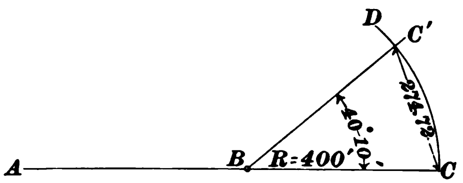


FIG 328.

From a table of chords, we find that the chord of an angle of 40° 10′ in terms of a radius 1 is .6868. Multiplying this chord by 400 ft., the length of the assumed radius, we have 274.72 ft., the length of the required chord. From *B* as a center, with a radius *B C* = 400 ft., describe to the left of *B C* the indefinite arc *C D*, being sure that the length of *C D* is slightly greater than the length of the required chord, and from *C* as a center, with a radius of 274.72 ft., describe an arc intersecting the arc *C D* in *C′*. Through

B and C' draw a straight line. The angle $C\ B\ C'$ is $40°\ 10'$, the required angle. This method of platting angles is more accurate, though less rapid, than platting with a protractor.

NOTE.—The table of chords used for the calculations given in this Course may be found in Trautwine's Pocket Book, a very useful book to all surveyors. If the student does not possess a copy, he may easily find the required chord from his table of sines by multiplying the sine of half the given angle by 2. Thus, the chord of $40°\ 10' = 2 \sin \frac{40°\ 10'}{2} = 2 \sin 20°\ 05' = 2 \times .34339 = .68678 = .6868$, using but four places, the same as given in the table.

1351. Fig. 2, same plate as above, contains three examples in the lines *a*, *b*, and *c*, in which the angles are laid off by chords. The notes for example *a* are given in the accompanying table.

The first course $A\ B$ is 360 feet in length, which the student will draw to a scale of 200 feet to the inch. The starting point A is numbered 0, and B, the end of the first course, 3+60. At B an angle of $30°\ 30'$ is laid off to the right. Produce $A\ B$ 400 feet, which we assume to be the length of the radius in calculating chord lengths for laying off angles, and locate the point C. Then, from B as a center, with a radius of 400 feet, describe the indefinite arc $C\ C'$ on the right side of the radius $B\ C$, being sure that the arc shall contain at least $30°\ 30'$. We find in a *table of chords* that the chord of $30°\ 30' = .5261$, which, multiplied by 400 ft., the length of the assumed radius, gives 210.44 ft., the length of the required chord. From C as a center, with a radius of 210.44 ft., describe an arc intersecting the arc $C\ C'$ in the point E. A line joining B and E will form with the radius $B\ C$ an angle $C\ B\ E = 30°\ 30'$, the required

NOTES FOR LINE *a*.

Stations.	Angles.
25 + 80	End of Line
20 + 38	L. 37° 20′
15 + 18	L. 31° 08′
9 + 13	R. 39° 26′
3 + 60	R. 30° 30′
0	

angle. The next angle R. 39° 26′ is turned at Sta. 9 + 13, making the length of the second course 553 ft. Denote Sta. 9 + 13 by *F*. Produce *B F* 400 ft. to *G*. From *F* as a center, with a radius *F G* of 400 ft., describe to the right of *F G* the indefinite arc *G G′*, being sure that the arc shall contain at least 39° 26′. The chord of 39° 26′ to a radius 1 is .6747, which, multiplied by 400 ft., gives 269.88 ft., the length of the required chord. From *F* as a center, with a radius of 269.88 ft., describe an arc intersecting the arc *G G′* in *H*. A line joining *F* and *H* will form with the radius *F G* the angle *G F H* = 39° 26′, the required angle. The next angle, viz., L. 31° 08′, is turned

NOTES FOR LINE *b*.

Stations.	Angles.
22 + 40	End of Line.
16 + 50	L. 18° 20′
8 + 60	R. 25° 14′
3 + 25	R. 8° 10′
0	

NOTES FOR LINE *c*.

Stations.	Angles.
25 + 34	End of Line.
19 + 94	L. 51° 22′
14 + 81	R. 21° 20′
10 + 38	R. 39° 18′
4 + 13	L. 64° 30′
0	

at Sta. 15 + 18, making the length of the third course 605 ft. Call Sta. 15 + 18, *K*. Produce *F K* 400 ft. to *L*. From *K* as a center, with a radius *K L* of 400 ft., describe to the left of *K L* the indefinite arc *L M*. The chord of 31° 08′ is .5367, which, multiplied by 400 ft., gives 214.68 ft., the length of the required chord. From *L* as a center, with a radius of 214.68 ft., describe an arc intersecting the arc *L M* in the point *N*. Join *K* and *N*, forming with *K L* the angle *L K N* = 31° 08′. The next angle, viz., L. 37° 20′, is turned at Sta. 20 + 38, making the length of the fourth course 520 ft. Call Sta. 20 + 38, *O*. Produce *K O* 400 ft. to *P*. From *O* as a center, with a radius *O P*, describe the indefi-

nite arc $P Q$. The chord of 37° 20′ is .6401, which, multiplied by 400 ft., gives 256.04 ft., the length of the required chord. From P as a center, with a radius of 256.04 ft., describe an arc intersecting the arc $P Q$ in R. Join O and R, forming with $O P$ the angle $P O R = 37° \; 20'$. The end of the line S is at Sta. 25 + 80, making the length of the last course 542 ft. In a similar manner, plat the notes for lines b and c, which are given in Art. **1353.**

1352. To Lay Off an Angle by its Bearing.—By this method of laying off angles, the direction of each line is referred to the magnetic meridian, which maintains a constant direction, being a north and south line. The bearing of a line is the angle which the line makes with the magnetic meridian. In platting a land or railroad survey, a pencil

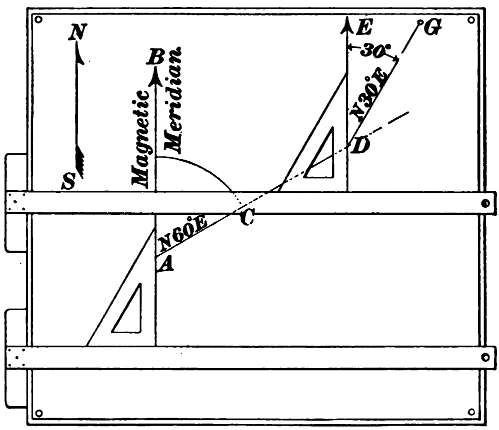


FIG. 329.

line giving the direction of the magnetic meridian is drawn through each station at which a bearing is taken.

The direction of the meridian may be given by means of the ordinary **T** square and triangles, and the angles laid off either by a protractor or by tangents. The use of **T** square and triangles in laying off angles by bearings is illustrated in Fig. 329. A sheet of paper is fastened to a drawing board. It is well known that if the head of the **T** square

be kept firmly pressed against the side of the drawing board, as shown in the figure, the lines drawn along the straight edge will be parallel; hence, the lines drawn perpendicular to this straight edge by means of the triangles, as shown in the figure, will be parallel.

Either the parallels drawn along the straight edge of the **T** square or of the triangle may be used as the magnetic meridian, though the latter is preferable, as it brings the north end of the meridian at the top of the map, which is its proper position.

Let it be required to plat a line having a bearing of N 60° E. As in Fig. 329, a point *A* is assumed as the station at which the bearing is taken. Through the point *A*, a line *A B* is drawn perpendicular to the straight edge of the **T** square. This line will represent the direction of the magnetic meridian. As the bearing is east, the angle of 60° will be to the right of *A B*. Place a protractor with its center at *A* and its zero point in the line *A B*. Lay off the angle 60°, and mark the point of measurement *C* with a needle point. Draw a line joining the starting point *A* with the point of angle measurement *C*. The line *A C* will then form an angle of 60° with the meridian, and its course will be N 60° E. From the notes find the length of the first course, and measure on the line *A C* to some convenient scale the length of that course, locating the point *D*, where the next bearing N 30° E is taken. Slide the **T** square upwards, and with the triangle draw through *D* another meridian *D E*. From *D* as a center lay off from the right of the meridian *D E* the bearing N 30° E. Let *F* mark the measurement of this angle. The line joining *D* and *F* will have a bearing of N 30° E.

PLATE, TITLE: PLATTING ANGLES II.

1353. This plate contains five angle lines, the angles of the three lines given in Fig. 1 being platted by *magnetic bearings*, and those in Fig. 2 by *tangents*. In Fig. 1, line ***a***, the distances are given in stations of 100 feet each; in the lines *b* and *c*, the distances are given in chains. The student

will draw line *a* to a scale of 200 feet to the inch, and lines *b* and *c* to a scale of 2 chains to the inch. The notes of line *a* are given below.

Let *A* be the starting point of the line, which we number Station 0. Let the arrow *N S* give the direction of the magnetic meridian. Through *A* draw a meridian *A B* parallel to *N S*. The bearing of the first course is N 10° 15′ E. From the meridian passing through *A* lay off this bearing angle with a protractor, as directed in Art. **1352.** The first course is 375 ft. Draw a line through *A* having the given bearing, and scale the distance 375 ft. This will bring us to Sta. 3 + 75, which we denote by the letter *C*, where a bearing of N 60° E is taken. The end of this course is at Sta. 6 + 90. The length of the second course will, therefore, be the difference between 6 + 90 and 3 + 75, which is 315 feet. Through *C* draw a meridian *C D*, from which lay off the bearing angle of 60° and draw a line marking the second course. Scaling the distance 315 feet we reach Sta. 6 + 90, which we call *E*. Here a bearing N 83° 30′ E is taken. Through *E* draw a meridian *E F*, and from it lay off the bearing N 83° 30′ E. The end of this course is at Sta. 10 + 40. Its length will, therefore, be the difference between 10 + 40 and 6 + 90, which is 350 ft.

NOTES FOR LINE a.

Stations.	Bearings.
28 + 15	End of line.
23 + 55	S 45° 00′ E
18 + 92	S 70° 45′ E
14 + 20	N 80° 30′ E
10 + 40	S 81° 20′ E
6 + 90	N 83° 30′ E
3 + 75	N 60° 00′ E
0	N 10° 15′ E

Scale off this distance from *E*, locating Sta. 10 + 40, which we call *G*. The bearing at *G* is S 81° 20′ E. Through *G* draw the meridian *G H*. As the bearing is S E, the meridian will fall below the station, from which lay off the bearing S 81° 20′ E, and draw a line in the direction of this course. The next bearing is taken at

Sta. 14 + 20. The length of the course is, therefore, the difference between 14 + 20 and 10 + 40, which is 380 ft. Call Sta. 14 + 20, *K*. Through *K* draw the meridian *K L*. The bearing here is N 80° 30′ E. From the meridian *K L*, lay off this bearing and draw a line in the direction of the course. In a similar manner locate the remaining stations and lay off the remaining bearings of the line. The bearing of each course should be distinctly written above it, the letters reading in the same direction in which the line is measured.

The notes for the lines *b* and *c* are as follows:

NOTES FOR LINE *b*.

Stations.	Bearings.	Distances.
1	N 40½° E	4.22 chains
2	N 65¼° E	6.75 chains
3	S 75½° E	8.70 chains
4	S 45¼° E	6.60 chains
5	S 20¼° W	5.18 chains

NOTES FOR LINE *c*.

Stations.	Bearings.	Distances.
1	S 47° E	6.60 chains
2	N 20¼° E	8.80 chains
3	S 80° E	4.32 chains
4	S 20° E	6.54 chains
5	N 65½° E	7.48 chains

1354. The regular 100-foot stationing is used in railroad and highway surveying, but in land surveying the lengths of the courses are given in surveyors' chains. As the fractional parts of chains are given decimally, the

length of each course is readily scaled on the plat with a decimal scale. The notes of line *b* are platted as follows: The starting point is called Sta. 1, and so marked on the plat. Call Sta. 1, *A*. Through *A* draw a meridian *A B*, and from it lay off the first bearing, N $40\frac{1}{2}°$ E. The first course is 4.22 chains in length, which lay off to a scale of 2 chains to the inch, locating Sta. 2, which call *C*. Through *C* draw a meridian *C D*, and lay off the given bearing N $65\frac{1}{4}°$ E. The course with this bearing is 6.75 chains in length, which scale off, locating Sta. 3. In similar manner plat the remainder of line *b*, and also line *c*. Mark distinctly each course, giving its direction and length, being careful that the figures and letters shall read in the same direction in which the line is being run.

1355. To Lay Off an Angle by its Tangent.—In laying off an angle by its tangent, the line from which the angle is turned is prolonged to a distance equal to the length of the assumed radius. The length of the tangent of the given angle is then found in terms of the assumed radius and the tangent platted. A line joining the angular point with the extremity of the calculated tangent will give the direction of the required line, which is then measured to the given scale.

Let *A B*, in Fig. 330, be the given line, from which an angle of 30° 15′ is to be laid off to the right at the point *B*. Produce *A B* to *C*, making $B\ C = 400$ feet, the length of the assumed radius. The tangent of 30° 15′ in terms of a radius 1, is .58318, which, multiplied by 400 feet, the length of the assumed radius, gives 233.27 feet, the length of the required tangent. At *C* erect a perpendicular to *B C* 233.27 feet in length, equal to the calculated tangent. Denote the end of this tangent by *C*′. Join *B* and *C*′. The angle $C\ B\ C' = 30°\ 15'$, the given angle, and the line *B C*′ is the required line.

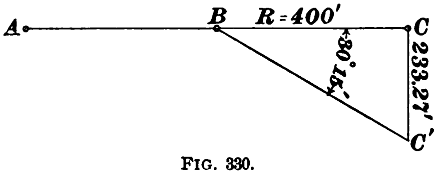


FIG. 330.

The following notes which are platted in Plate, Title: Platting Angles II, Fig. 2, the student will plat to a scale of 200 feet to the inch:

NOTES FOR LINE *a*.

Stations.	Angles.	Bearings.
25 + 00	End of Line	
19 + 97	L. 40° 10′	N 78° 45′ E
13 + 22	R. 32° 15′	S 61° 05′ E
5 + 00	R. 43° 30′	N 86° 40′ E
0		N 43° 10′ E

The notes for line *a* are platted as follows: Having adjusted the paper to the drawing board and drawn a meridian $N\ S$, fix the starting point A, which number 0. The first course is 500 feet in length, which plat by drawing a meridian $A\ B$ through Sta. 0, and scale off 400 ft. equal to the length of the assumed radius $A\ C$. The bearing of the first course is N 43° 10′ E. The tangent of 43° 10′ is .93797, which, multiplied by 400, the length of the radius, gives 375.19, the length of the required tangent. Erect a perpendicular to $A\ B$ at C, and on this perpendicular scale off to the right, the tangent 375.19 ft., calling the extremity of the tangent D. Draw $A\ D$. The angle $C\ A\ D$ will be 43° 10′. The first course is 500 feet in length, which scale off on the line $A\ D$ at 200 ft. to the inch, locating Sta. 5 + 00 at E. The angle at Sta. 5 + 00 is 43° 30′ to the right. Produce $A\ E$ and scale off the radius $E\ F = 400$ ft. The tangent of 43° 30′ = .94896, which, multiplied by 400, gives 379.58 ft., the length of the required tangent. Erect a perpendicular to $E\ F$ at F, and scale off, to the right, the tangent 379.58 ft., locating the point G. Draw $E\ G$. The angle $F\ E\ G$ is 43° 30′, and the line $E\ G$ the required line, the bearing of which is N 86° 40′ E. Produce $E\ G$ to H, making $E\ H = 1{,}322 - 500 = 822$ ft. in length.

The line changes direction again at Sta. 13 + 22, where an angle of 32° 15′ is turned to the right. Denote Sta. 13 + 22 by *H*. Produce *E H* 400 feet, equal to the assumed radius, calling its extremity *K*. The tangent of 32° 15′ = .63095, which, multiplied by 400 feet, gives 252.38 feet, the length of the required tangent. Erect a perpendicular to *H K* at *K* and on that perpendicular scale off, to the right, the tangent 252.38 feet, locating the point *L*. Join *H* and *L*. The angle *K H L* is 32° 15′ and the bearing of *H L* is S 61° 05′ E.

The line changes direction again at Sta. 19 + 97. Call this station *M*. The angle at this point is 40° 10′ to the left. Produce *H M* 400′ to *N*, and at *N* erect a perpendicular to *M N*. The tangent of 40° 10′ is .84407, which, multiplied by 400, gives 337.63 feet, the length of the required tangent. On the perpendicular to *M N* scale off, to the left, this tangent, locating the point *O*. Join *M* and *O*. The end of the line is Sta. 25 + 00. The length of the last course is readily found by subtracting 19 + 97 from 25 + 00. The difference, 503 feet, is scaled off on *M O*, locating the point *P*, the end of the line. The bearing of *M P* is N 78° 45′ E. In a similar manner plat the notes of line *b*.

NOTES FOR LINE *b*.

Stations.	Angles.	Bearings.
27 + 47	End of Line	
20 + 97	R. 42° 20′	S 34° 25′ E
13 + 73	R. 49° 10′	S 76° 45′ E
7 + 63	L. 62° 15′	N 54° 05′ E
0		S 63° 40′ E

1356. To Lay Off an Angle by Latitude and Departure.—The subject of latitudes and departures was discussed in the section on Land Surveying, and the theory needs no explanation in connection with this subject.

Suppose the bearing of a line is N 40° E, and its length is 300 feet. Its latitude and departure are calculated as follows:

Distances.	Latitudes.	Departures.
3 0 0 ft.	2 2 9 8	1 9 2 8
0 0 ft.	0 0 0 0	0 0 0 0
0 ft.	0 0 0 0	0 0 0 0
3 0 0 ft.	+ 2 2 9.8 ft.	+ 1 9 2.8 ft.

The student should bear in mind that north latitudes and east departures are +, and south latitudes and west departures are —.

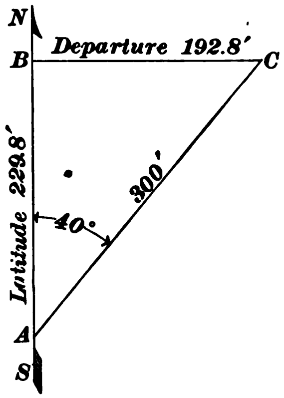


FIG. 331.

Let A, in Fig. 331, be the station at which the bearing is taken. Through A draw the meridian $N\ S$. From A upwards scale the calculated latitude 229.8 ft., marking the extremity B. At B erect a perpendicular to the meridian $N\ S$, drawing it from left to right, as the bearing is east. On this perpendicular scale off the calculated departure 192.8 ft., locating the point C. Join A and C. The angle $B\ A\ C$ is 40°, equal to the given bearing, and $A\ C$ is equal to the length of the given course, viz., 300 ft.

EXAMPLE.—Calculate the latitudes and departures of the following courses, and plat them by means of total latitudes and total departures from Sta. 1.

Stations.	Bearings.	Distances.	Latitudes.		Departures.	
			N +	S −	E +	W −
1	N $10\frac{1}{4}$° E	250 ft.	246 ft.		44.5 ft.	
2	N $41\frac{3}{4}$° E	123 ft.	91.76 ft.		81.92 ft.	
3	N $84\frac{1}{2}$° E	215 ft.	20.64 ft.		214.03 ft.	
4	S $25\frac{1}{4}$° E	210 ft.		189.94 ft.	89.57 ft.	

SOLUTION.—

Distances.	Latitudes.	Departures.
250 ft.		
200 ft.	1968	0356
50 ft.	4920	0890
0 ft.	0000	0000
250 ft.	246.000 ft.	44.500 ft.
123 ft.		
100 ft.	0746	0666
20 ft.	1492	1332
3 ft.	2238	1998
123 ft.	91.758 ft.	81.918 ft.
215 ft.		
200 ft.	0192	1991
10 ft.	0096	0995
5 ft.	0479	4977
215 ft.	20.639 ft.	214.027 ft.
210 ft.		
200 ft.	1809	0853
10 ft.	0904	0427
0 ft.	0000	0000
210 ft.	189.940 ft.	89.570 ft.

Stations.	Total Latitudes from Station 1.	Total Departures from Station 1.
1	0.00 ft.	0.00 ft.
2	+ 246.00 ft.	+ 44.50 ft.
3	+ 337.76 ft.	+ 126.42 ft.
4	+ 358.40 ft.	+ 340.45 ft.
5	+ 168.46 ft.	+ 430.02 ft.

The platting of the courses is as follows: On the meridian *N S*, Fig. 332, take a point which call Sta. 1. The total latitude of Sta. 2 is + 246 feet, and, as it is a plus latitude, it must be scaled off on the meridian above Sta. 1, locating

the point A. The total departure of Sta. 2 is + 44.5 feet. This departure will therefore be to the right of the meridian $N S$. At A, erect a perpendicular to the meridian, and upon it scale off the total latitude 44.5 feet, locating Sta. 2. The line joining Stas. 1 and 2, i. e., the first course, will have a bearing of N $10\frac{1}{4}°$ E. Its length, viz., 250 feet, we write on the plat, the figures reading in the same direction in which the line is being run.

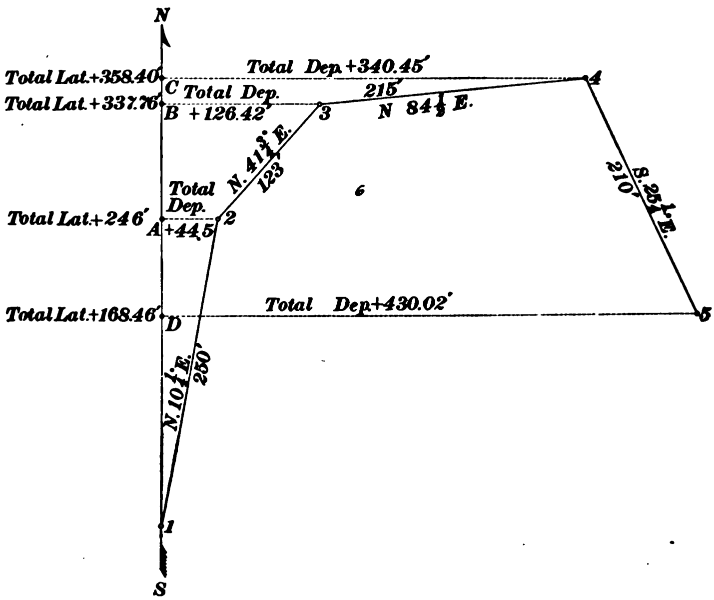


FIG. 332.

The total latitude of Sta. 3 is +337.76 feet, which we scale off on the meridian above Sta. 1, locating the point B, and on a perpendicular to the meridian at B, we scale off the total departure of Sta. 3, which is + 126.42 feet, locating Sta. 3. The line joining Stas. 2 and 3 has a bearing of N $41\frac{3}{4}°$ E, and length of 123 feet. The total latitude of Sta. 4 is + 358.4 feet, which we scale off on the meridian above Sta. 1, locating the point C, where we erect a perpendicular to the meridian and upon it scale off the total departure of Sta. 4,

viz., + 340.45 feet, locating Sta. 4. The line joining Stas. 3 and 4 will have a bearing of N $84\frac{1}{2}°$ E, and a length of 215 feet. The total latitude of Sta. 5 is + 168.46 feet, which we scale off on the meridian locating the point *D*, where we erect a perpendicular to the meridian and upon it scale off the total departure of Sta. 5, viz., + 430.02 ft., locating that point. The line joining Stas. 4 and 5 has a bearing of S $25\frac{1}{4}°$ E, and a length of 210 ft. This method of platting bearings or angles is more accurate than either of the foregoing methods, as each course is platted independently. Great care must, however, be observed in making the additions by which total latitudes and departures are obtained. Tables of latitudes and departures are commonly calculated to quarter degrees. See table of Latitudes and Departures. Where angles are read to single minutes, a table of sines and cosines may be used to advantage. The two following formulas should be memorized:

$$\text{Latitude} = \text{distance} \times \cos \text{bearing}. \qquad \textbf{(97.)}$$

$$\text{Departure} = \text{distance} \times \sin \text{bearing}. \qquad \textbf{(98.)}$$

1357. In preliminary railroad work, angles are commonly platted by tangents, but on difficult parts of the line where all dependence must be placed on a paper location, latitudes and departures should be used and the line platted to a scale that will admit of full topographical details.

For practice in platting lines by latitudes and departures, the following examples are given. The notes of Example 1 are platted in Fig. 333, and those of Example 2 are platted in Fig. 334.

The student should carefully study the different steps given under Art. **1356,** and illustrated in Fig. 332, before undertaking to plat the following notes. He should calculate the latitudes and departures for each course, comparing his results with those given in the text and likewise with the total latitudes and departures for platting. These plats he will submit for inspection, together with Plate, Title: Platting Angles II.

EXAMPLE 1.

Stations.	Bearings.	Distances.	Latitudes.		Departures.		Total Latitudes from Station 1.	Total Departures from Station 1.
			N +	S −	E +	W −		
1	N $29\frac{3}{4}°$ E	4.33 ch.	375.9 li.	....	214.9 li.	....	0.0 li.	0.0 li.
2	N $80\frac{1}{2}°$ E	5.17 ch.	85.3 li.	....	509.9 li.	....	+ 375.9 li.	+214.9 li.
3	N $89\frac{1}{4}°$ E	4.07 ch.	5.3 li.	....	407.0 li.	....	+ 461.2 li.	+724.8 li.
4	S 10° E	6.40 ch.	....	630.3 li.	111.1 li.	....	+ 466.5 li.	+1,131.8 li.
5	S 21° W	7.11 ch.	....	663.8 li.	....	254.8 li.	− 163.8 li.	+1,242.9 li.
6	N $31\frac{1}{4}°$ W	5.20 ch.	444.6 li.	....	....	269.8 li.	− 827.6 li.	+988.1 li.
7	N $51\frac{1}{4}°$ W	4.45 ch.	278.6 li.	....	....	347.1 li.	− 383.0 li.	+718.3 li.
8	S $27\frac{1}{2}°$ W	5.85 ch.	....	518.9 li.	....	270.1 li.	− 104.4 li.	+371.2 li.
9	End of Line.		....	....	....	....	− 623.3 li.	+101.1 li.

EXAMPLE 2.

Stations.	Bearings.	Distances.	Latitudes.		Departures.		Total Latitudes from Station 1.	Total Departures from Station 1.
			N +	S −	E +	W −		
1	N $14\frac{1}{2}°$ W	798 ft.	772.6 ft.	....	....	199.8 ft.	....	....
2	N $89\frac{3}{4}°$ W	453 ft.	1.9 ft.	....	....	453.0 ft.	+ 772.6 ft.	−199.8 ft.
3	S $49\frac{1}{4}°$ W	445 ft.	....	290.5 ft.	....	337.1 ft.	+ 774.5 ft.	−652.8 ft.
4	S $60\frac{3}{4}°$ E	608 ft.	....	297.1 ft.	530.5 ft.	....	+ 484.0 ft.	−989.9 ft.
5	S $70\frac{1}{2}°$ W	510 ft.	....	170.2 ft.	....	480.7 ft.	+ 202.8 ft.	−459.4 ft.
6	S $30\frac{1}{2}°$ W	387 ft.	....	333.5 ft.	....	196.4 ft.	+ 32.6 ft.	−940.1 ft.
7	S $66\frac{1}{4}°$ E	648 ft.	....	260.9 ft.	593.1 ft.	....	− 300.9 ft.	−1,136.5 ft.
8	N 48° E	615 ft.	411.5 ft.	....	457.0 ft.	....	− 561.8 ft.	−543.4 ft.
9	End of Line.		....	....	....	....	− 150.3 ft.	−86.4 ft.

A piece of drawing paper one-half the size of an ordinary drawing plate will be large enough to contain plats of both lines. The total latitudes and departures in both examples are reckoned from Station 1, which in Fig. 333 is the most westerly station, and in Fig. 334 the most easterly one. Plat the courses of Example 1 to a scale of 2 chains to the inch, and those of Example 2 to a scale of 200 feet to the inch.

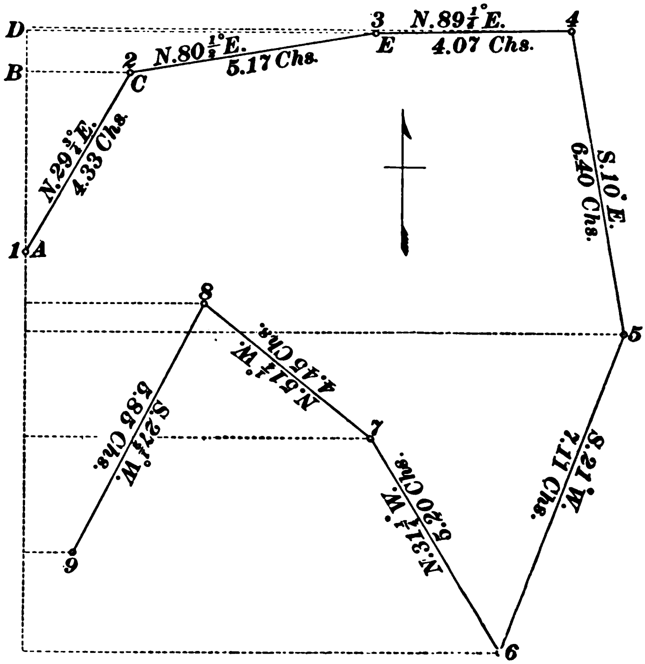


FIG. 333.

In Fig. 333, a magnetic meridian is drawn through Sta. 1, which we call *A*. We find in the column for total latitudes and departures from Sta. 1 (see Example 1), that the total latitude of Sta. 2 is + 375.9 links, which we scale off on the meridian above *A* to a scale of 2 chains or 200 links to the inch, locating the point *B*. The total departure of Sta. 2 is + 214.9 links, which we scale off at 2 chains to the inch on a

perpendicular to the meridian at B, locating Sta. 2, which we call C. A line joining A and C will have the given length and bearing of the first course, viz., length 4.33 chains, and bearing N $29\frac{3}{4}°$ E.

The total latitude of Sta. 3 is $+$ 461.2 links, which we scale upon the meridian above A at 2 chains or 200 links to the inch, locating the point D. The total departure of Sta. 3 is $+$ 724.8 links, which we scale off on a perpendicular to the

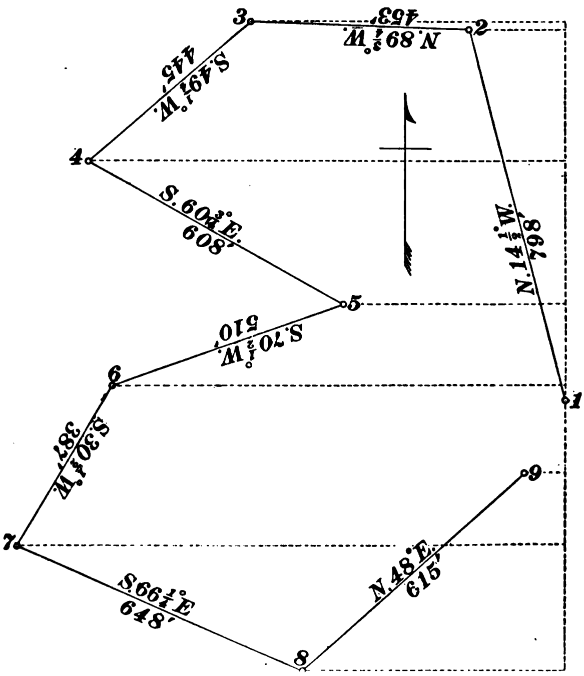


FIG. 334.

meridian at D, locating Sta. 3, which we call E. A line joining C and E will have the given length and bearing of the second course, viz., length 5.17 chains, and bearing N $80\frac{1}{2}°$ E. In a similar manner plat the remaining courses, bearing in mind that positive latitudes are measured on the meridian above Sta. 1, and positive departures on perpendiculars to the right of the meridian, while negative latitudes

are measured on the meridian below Sta. 1, and negative departures, if there were any, on perpendiculars to the left of the meridian. The notes for Example 2 are similarly platted, excepting that the meridian passes through the most easterly station, as all the departures from Sta. 1 are negative. The lengths of the courses in this example are given in feet, and are to be platted to a scale of 200 feet to the inch. Write the bearing of each line distinctly, being careful that the letters read in the same direction in which the line is run. The student is expected to accompany each drawing with a brief description of the successive steps taken in the work.

1358. Parallel Rulers.—A parallel rule is a straight edge carried on milled rollers of equal diameter, having a common axis. They are of great service in drawing meridian lines. A magnetic meridian is drawn the entire width of the sheet which is to contain the plat. The straight edge of the rule is then made to coincide with the meridian line and then rolled across the paper until the straight edge passes through the point where the angle is to be measured. A line is then drawn following the straight edge; this will be a meridian line.

1359. The Line of Survey.—The line of **preliminary survey** is a succession of straight lines and angles, or an **angle line,** as it is commonly called, while the **located line** is a succession of straight lines and curves.

1360. Tangents and Curves.—Though this subject has been considered in the section on Surveying, yet some additional matter may be of advantage in connection with the subject of mapping.

1361. Map of Final Location.—In mapping a final location the measurements should be made from intersection point to intersection point, and the angles platted either by tangents or by latitudes and departures. The points of curve are then located by scaling the tangent distances from the intersection points. The curve centers

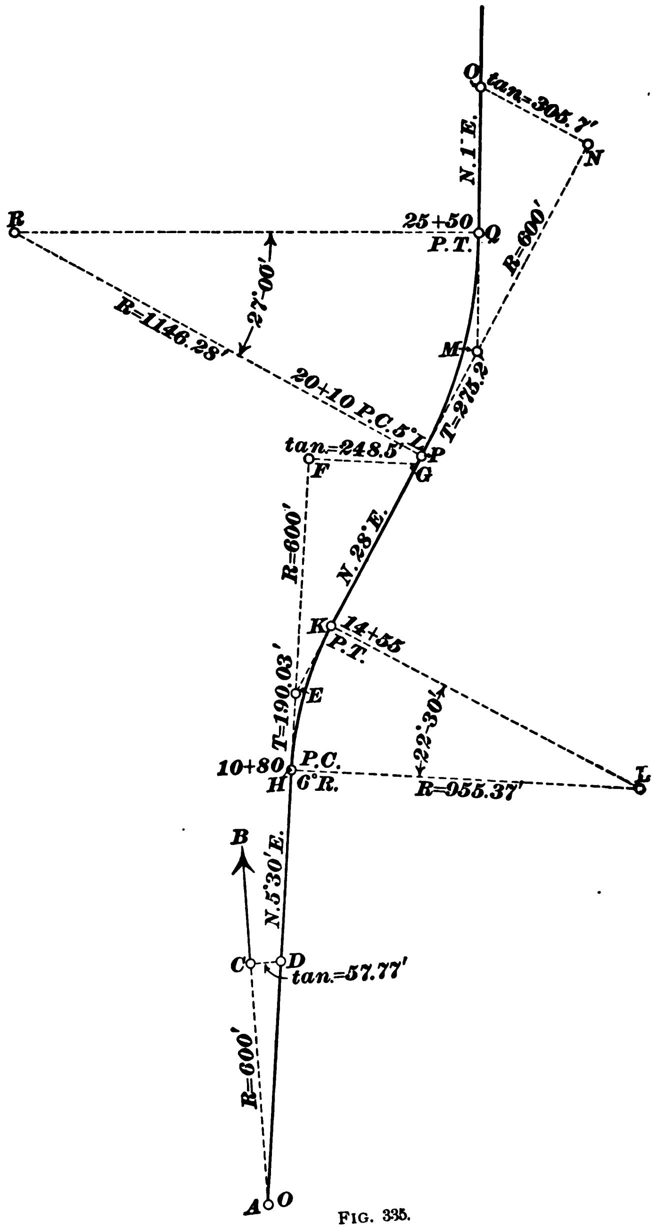

O
tan.=305.7′
N
N. 1° E.
R
25+50
Q
P.T.
R=600′
27°00′
R=1146.28′
M
20+10 P.C. 5° L.
T=275.2′
tan.=248.5′
P
F
G
R=600′
N. 28° E.
K
14+55
P.T.
T=190.03′
E
22°30′
10+80
P.C.
H
6° R.
R=955.37′
L
B
N. 5° 30′ E.
C
D
tan.=57.77′
R=600′
A
O

FIG. 335.

are best determined by describing intersecting arcs from the tangent points as centers, with radii equal to that of the given curve.

Let it be required to plat by tangents the following location notes:

Stations.	Degree of Curve.	Intersection Angle.	Tangent.	Magnetic Bearing.
25 + 50	P. T.	....	....	N 1° 00′ E
20 + 10	P. C. 5° L.	27° 00′	275.20 ft.	....
14 + 55	P. T.	....	....	N 28° 00′ E
10 + 80	P. C. 6° R.	22° 30′	190.03 ft.	....
0	....	....	....	N 5° 30′ E

The tangent distances are found by the formula

$$T = R \tan \tfrac{1}{2} I.$$

(See Art. **1251.**) The first curve is 6° R.; the intersection angle I is 22° 30′. The radius of a 6° curve is 955.37 feet. See table of Radii and Chord and Tangent Deflections.

$\frac{1}{2} I = 11° \ 15'$. Tan $11° \ 15' = .19891$; then $955.37 \times .19891$ ft. $= 190.03$ ft. $= T$, which we place in the column headed "tangent," opposite the intersection angle 22° 30′. The second curve is 5° L; the intersection angle is 27° 00′. The radius of a 5° curve is 1,146.28 feet. $\frac{1}{2} I = 13° \ 30'$. Tan $13° \ 30' = .24008$, and 1,146.28 ft. $\times$ .24008 $=$ 275.2 ft. $= T$, which we place in tangent column opposite the intersection angle 27° 00′.

A plat of these notes is given in Fig. 335. The order of work is the following: First we select a starting point A, which we number 0, and through this point draw a meridian $A\ B$ with its north point at the top of the plat.

The first course has a bearing N 5° 30′ E. From Station 0, scale off on the meridian 600 feet, the length of our radius for platting angles. The bearing angle is 5° 30′ and

its tangent .09629, which, multiplied by 600, the radius, gives 57.77 feet, the length of the required tangent. Call the extremity of the radius *C*. At *C* erect a perpendicular to *A B*, and on it lay off the tangent 57.77 feet, locating the point *D*. Join *A* and *D*. The angle $C A D = 5° 30'$. The P. C. of the first curve is at Station $10 + 80$. The tangent distance, as given in the preceding table, is 190.03 feet. Hence, the distance from the starting point to the first intersection point is the sum of 1,080 and 190.03 feet, which is 1,270.03 feet. Produce *A D*, making a total distance of 1,270.03 feet to the point of intersection *E*, and 600 feet additional for the radius by which the next angle is platted. Call the extremity of this radius *F*. The intersection angle of the first curve is 22° 30′. Its tangent is .41421, which, multiplied by 600, the given radius, gives 248.52 feet as the required tangent for platting the angle. At *F* erect a perpendicular to the radius *E F* and scale off the tangent $F G = 248.52$ feet, locating the point *G*. Join *E* and *G*. The angle *F E G* is 22° 30′, and the bearing of the tangent *E G* is N 28° E. Next, from the point of intersection *E*, scale off on the lines *E D* and *E G* the tangent distance 190.03 feet, locating the P. C. at *H*, Station $10 + 80$, and the P. T. at *K*, Station $14 + 55$. Now, from *H* and *K* as centers with a radius 955.37 feet = radius of 6° curve, describe arcs intersecting at the point *L*. Then, from *L* as a center with the same radius, describe a curve joining the points *H* and *K*. The curve *H K* will be a 6° curve and will be tangent to the lines *H D* and *K G* at the points of curve *H* and *K*. The next intersection point *M* is in the line *E G* produced. The distance between these intersection points is made up of three parts, viz., the tangent of preceding curve, which we know to be 190.03 feet; the intermediate tangent, i. e., the distance from the P. T. of the first curve to the P. C. of the second curve, and the tangent of the next curve following. The P. T. of the first curve is at Station $14 + 55$; the P. C. of the second curve is at Station $20 + 10$; the intermediate tangent is, therefore, the difference between $14 + 55$ and $20 + 10$, which is 555 feet.

The tangent of the second curve is 275.2 feet. Hence, the distance from the intersection point E of the first curve to the intersection point M of the second curve is the sum of 190.03, 555, and 275.2 ft., which is 1,020.23 ft. Produce $E\ G$ so as to contain 1,020.23 ft., and 600 additional feet for a radius, the extremity of which call N. The intersection angle of the second course is $27^\circ\ 00'$ L., tan $27^\circ = .50953$. Radius 600 ft. $\times$ .50953 = 305.72 ft., the length of the required tangent. Accordingly, at N we erect a perpendicular to the radius $M\ N$, and on that perpendicular, scale off the tangent 305.72 feet, locating the point O. Join M and O. The angle $N\ M\ O$ is $27^\circ\ 00'$, equal to the given intersection angle, and the bearing of the tangent $M\ O$ is N 1° E. From M on the lines $M\ K$ and $M\ O$ scale off the tangent distance 275.20 feet, locating the P. C. at P, Sta. 20 + 10, and the P. T. at Q, Sta. 25 + 50. Then, from P and Q as centers with radii of 1,146.28 feet, the radius of a 5° curve, describe arcs intersecting at R. From R as a center with the same radius describe the curve $P\ Q$, which is a 5° curve, and is tangent to the lines $M\ K$ and $M\ O$ at P and Q. Write the bearing of each tangent in its proper place, being careful that the bearings shall read in the same direction in which the line is being run.

PLATE, TITLE: MAP OF RAILROAD LOCATION.

1362. This plate contains two maps of railroad location, Figs. 1 and 2, the notes for which are given in the following pages. All the angles are laid off by tangents and the notes of the *alinement* given in detail, all of which the student must carefully go over and check.

The student, before commencing these drawings, should first note that the magnetic meridian (by means of which the direction of the first tangent of each line is determined) is parallel to the right and left border lines of the plate. He must also determine by measurement from the border lines the location of the starting point 0 of each line.

Without these precautions, the lines are liable to run off the paper, necessitating a repetition of the work, and involving the erasure of lines, which always soils the paper and mars the appearance of the drawing.

He will make the drawing to a scale of 300 feet to the inch. If his scale reads only 200 feet to the inch, he will reduce the distances given to a scale of 300 feet to the inch, to their equivalent to a scale of 200 feet to the inch. The process of reduction is simple and may be readily understood from the following: A line which measures 300 feet in length to a scale of 300 feet to the inch will measure but 200 feet to a scale of 200 feet to the inch. Hence, in changing a scale from 300 feet to 200 feet to the inch the distances and dimensions will scale but $\frac{2}{3}$ of the original distances and dimensions.

EXAMPLE.—A line measures 963 feet to a scale of 300 feet to the inch. What will it measure to a scale of 200 feet to the inch?

SOLUTION.—$\frac{2}{3}$ of $963 = 642$, i.e., to a scale of 200 feet to the inch, the line will measure 642 feet.

1363. The order of platting the notes is as follows: First draw a meridian as indicated by the arrow. Next, having located the starting point A, Fig. 1, which is numbered 0, draw through that station a parallel meridian $A\ B$. We find from the notes that the direction of the back tangent $A\ A'$ (which we will consider a part of a line of railroad already constructed) is due north and south, and that Sta. 0 is the P. C. of an 8° R. curve with a central or intersection angle of 63° 10′. The tangent distance we find by the formula $T = R \tan \frac{1}{2} I$, is 440.7 feet. This distance we scale off on the meridian above the point A to a scale of 300 ft. to the inch, locating the point C, which is the intersection point of the back and forward tangents.

Next, from C on the same meridian, we scale off the radius $C\ D$ of 400 feet for laying off the angle of the first curve. The angle of this curve is 63° 10′. The tan of 63° 10′ is 1.97681. The radius 400 ft. $\times$ 1.97681 = 790.7 ft., the length of the required tangent. At D erect a perpendicular to

NOTES FOR FIG. 1.

Station.	Deflection.	Total Angle.	Magnetic Course.	Calculated Course.
40	12° 00′	....	....	....
39	6° 00′	....	....	....
38 + 00	18° 00′	36° 00′	....	....
37	12° 00′	....	....	....
36	6° 00′	....	....	....
35 + 00	P. C. 12° L.	....	....	....
34	....	....	....	....
33 + 04.9	10° 40.3′ P. T.	35° 50′	S 36° 30′ E	S 36° 40′ E
33	10° 30′	....	....	....
32	7° 00′	....	....	....
31	3° 30′	....	....	....
30	7° 14.7′	14° 29.4′	....	....
29	3° 44.7′	....	....	....
28	0° 14.7′	....	....	....
27 + 93	P. C. 7° R.	....	....	....
24	....	....	....	....
21	....	....	....	....
20 + 54.9	10° 38.8′ P. T.	44° 20′	S 72° 30′ E	S 72° 30′ E
20	9° 00′	....	....	....
19	6° 00′	....	....	....
18	3° 00′	....	....	....
17	11° 31.2′	23° 02.4′	....	....
16	8° 31.2′	....	....	....
15	5° 31.2′	....	....	....
14	2° 31.2′	....	....	....
13 + 16	P. C. 6° R.	....	....	....
12	....	....	....	....
11	....	....	....	....
10	....	....	....	....
9	....	....	....	....
8	....	....	....	....
7 + 89.6	15° 35′ P. T.	63° 10′	N 63° 00′ E	N 63° 10′ E
7	12° 00′	....	....	....
6	8° 00′	....	....	....
5	4° 00′	....	....	....
4	16° 00′	32° 00′	....	....
3	12° 00′	....	....	....
2	8° 00′	....	....	....
1	4° 00′	....	....	....
0	P. C. 8° R.	....	North	North

NOTES FOR FIG. 1.

	Remarks. June 28, 1894.
Int. Ang. $= 72^\circ 00'$ 12° curve, L. R. $= 478.34$ ft. T. $= 347.5$ ft. P. C. $= 35 + 00$ Length curve $= 600$ ft. P. C. C. $= 41 + 00$ Def. 100 ft. $= 6^\circ 00'$ Def. 1 ft. $= 3.6'$	From intersection to intersection. Tan preceding curve $=$ 264.8 ft. Tan between curves $=$ 195.1 ft. Tan 12° curve $=$ 347.6 ft. Total, $=$ 807.5 ft. $\tan 72^\circ 00' = 3.07768$ $400 \text{ ft.} \times 3.07768 = 1{,}231.1$ ft.
Int. Ang. $= 35^\circ 50'$ 7° curve, R. R. $= 819.02$ ft. T. $= 264.8$ ft. P. C. $= 27 + 93$ Length curve $= 511.9$ ft. P. T. $= 33 + 04.9$ Def. 100 ft. $= 3^\circ 30'$ Def. 1 ft. $= 2.1'$	From intersection to intersection. Tan preceding curve $=$ 389.2 ft. Tan between curves $=$ 738.1 ft. Tan 7° curve $=$ 264.8 ft. Total, $= 1{,}392.1$ ft. $\tan 35^\circ 50' = .72211$ $400 \text{ ft.} \times .72211 =$ 288.8 ft.
Int. Ang. $= 44^\circ 20'$ 6° curve, R. R. $= 955.37$ ft. T. $= 389.2$ ft. P. C. $= 13 + 16$ Length of curve $= 738.9$ ft. P. T. $= 20 + 54.9$ Def. 100 ft. $= 3^\circ 00'$ Def. 1 ft. $= 1.8'$	From intersection to intersection. Tan preceding curve $=$ 440.7 ft. Tan between curves $=$ 526.4 ft. Tan 6° curve $=$ 389.2 ft. Total, $= 1{,}356.3$ ft. $\tan 44^\circ 20' = .977$ $400 \text{ ft.} \times .977 =$ 390.8 ft.
Int. Ang. $= 63^\circ 10'$ 8° curve, R. R. $= 716.78$ ft. T. $= 440.7$ ft. P. C. $= 0$ Length of curve $= 789.6$ ft. P. T. $= 7 + 89.6$ Def. 100 ft. $= 4^\circ 00'$ Def. 1 ft. $= 2.4'$	Radius 1 $= 400$ ft. $\tan 63^\circ 10' = 1.97681$ $400 \text{ ft.} \times 1.97681 = 790.7$ ft.

NOTES FOR FIG. 2.

Station.	Deflection.	Total Angle.	Magnetic Course.	Calculated Course.
13 + 41.7	10° 15′ P. T.	32° 30′	S 79° 00′ E	S 79° 00′ E
13	9° 00′			
12	6° 00′			
11	3° 00′			
10 + 00	6° 00′	12° 00′		
9	3° 00′			
8 + 00	P. C. 6° R.			
5				
3				
0			S 46° 30′ E	

NOTES FOR FIG. 1—*Continued.*

Station.	Deflection.	Total Angle.	Magnetic Course.	Calculated Course.
69 + 10.1		End	of Line.	
61 + 65.1	15° 40′ P. T.	31° 20′	N 39° 45′ E	N 39° 40′ E
61	12° 44.1′			
60	8° 14.1′			
59	3° 44.1′			
58 + 17	P. C. 9° R.			
55				
54				
53				
52				
51				
50 + 00	17° 30′ P. T.	63° 00′	N 8° 15′ E	N 8° 20′ E
49	14° 00′			
48	10° 30′			
47	7° 00′			
46	3° 30′			
45	14° 00′	28° 00′		
44	10° 30′			
43	7° 00′			
42	3° 30′			
41 + 00	18° 00′ P. C. C. 7° L.	72° 00′	N 71° 15′ E	N 71° 20′ E

NOTES FOR FIG. 2.

	Remarks.	June 28, 1894.
Int. Ang. = 32° 30′ 6° curve, L. R. = 955.37 ft. T. = 278.5 ft. P. C. = 8 + 00 Length curve = 541.7 ft. P. T. = 13 + 41.7 Def. 100 ft. = 3° 00′ Def. 1 ft. = 1.8′	Radius 1 = 400.0 ft. From Sta. 0 to P. C. = 800.0 ft. Tan 6° curve = 278.5 ft. Total from P.C. to P.I. = 1,078.5 ft. tan 32° 30′ = .63707 400 ft. × .63707 = 254.8 ft.	

NOTES FOR FIG. 1—*Continued.*

	Remarks.	June 28, 1894.
Int. Ang. = 31° 20′ 9° curve, R. R. = 637.27 ft. T. = 178.7 ft. P. C. = 58 + 17 Length curve = 348.1 ft. P. T. = 61 + 65.1 Def. 100 ft. = 4° 30′ Def. 1 ft. = 2.7′	From intersection to intersection. Tan preceding curve = 501.9 ft. Tan between curves = 817.0 ft. Tan 9° curve = 178.7 ft. Total, = 1,497.6 ft. tan 31° 20′ = .60881 400 ft. × .60881 = 243.5 ft.	
Int. Ang. = 63° 00′ 7° curve, L. R. = 819.02 ft. T. = 501.9 ft. P. C. C. = 41 + 00 Length curve = 900 ft. P. T. = 50 + 00	From intersection to intersection. Tan preceding curve = 347.6 ft. Tan between curves = 0.0 ft. Tan 7° curve = 501.9 ft. Total, = 849.5 ft. tan 63° = 1.96261 400 ft. × 1.96261 = 785 ft.	

NOTES FOR FIG. 2—*Continued.*

Station.	Deflection.	Total Angle.	Magnetic Course.	Calculated Course.
57 + 40		End	of Line.	
47 + 19	8° 46.3′ P. T.	34° 00′	N 11° 15′ E	N 11° 20′ E
47	8° 15′	....	....	....
46	5° 30′	....	....	....
45	2° 45′	....	....	....
44 + 00	8° 13.7′	16° 27.4′	....	....
43	5° 28.7′	....	....	....
42	2° 43.7′	....	....	....
41 + 00.8	14° 01.7′ P.C.C. 5° 30′ L.	52° 00′	N 45° 15′ E	N 45° 20′ E
41	14° 00′	....	....	....
40	10° 30′	....	....	....
39	7° 00′	....	....	....
38	3° 30′	....	....	....
37 + 00	11° 58.2′	23° 56.4′	....	....
36	8° 28.2′	....	....	....
35	4° 58.2′	....	....	....
34	1° 28.2′	....	....	....
33 + 58	P. C. 7° L.	....	....	....
32	....	....	....	....
30 + 36.6	13° 27.8′ P. T.	48° 10′	S 82° 30′ E	S 82° 40′ E
30	12° 00′	....	....	....
29	8° 00′	....	....	....
28	4° 00′	....	....	....
27 + 00	10° 37.2′	21° 14.4′	....	....
26	6° 37.2′	....	....	....
25	2° 37.2′	....	....	....
24 + 34.5	P. C. 8° L.	....	....	....
24	....	....	....	....
23	....	....	....	....
22 + 14.4	9° 39′ P. T.	44° 30′	S 34° 20′ E	S 34° 30′ E
22	9° 00′	....	....	....
21	4° 30′	....	....	....
20 + 00	12° 36′	25° 12′	....	....
19	8° 06′	....	....	....
18	3° 36′	....	....	....
17 + 20	P. C. 9° L.	....	....	....
17	....	....	....	....
15	....	....	....	....

NOTES FOR FIG. 2—*Continued.*

	Remarks. June 28, 1894.
Int. Ang. = 34° 00′	From intersection to intersection.
5° 30′, L. R. = 1,042.14 ft.	Tan preceding curve = 399.5 ft.
T. = 318.6 ft.	Tan between curves = 0.0 ft.
P. C. C. = 41 + 00.8	Tan 5° 30′ curve = 318.6 ft.
Length curve = 618.2 ft.	Total, = 718.1 ft.
P. T. = 47 + 19	tan 34° 00′ = .67451
Def. 100 ft. = 2° 45′	400 ft. × .67451 = 269.8 ft.
Def. 1 ft. = 1.65′	
Int. Ang. = 52° 00′	From intersection to intersection.
7° curve, L. R. = 819.02 ft.	Tan preceding curve = 320.4 ft.
T. = 399.5 ft.	Tan between curves = 321.4 ft.
P. C. = 33 + 58	Tan 7° curve = 399.5 ft.
Length curve = 742.8 ft.	Total, = 1,041.3 ft.
P. C. C. = 41 + 00.8	tan 52° 00′ = 1.27994
Def. 100 ft. = 3° 30′	400 ft. × 1.27994 = 512 ft.
Def. 1 ft. = 2.1′	
Int. Ang. = 48° 10′	From intersection to intersection.
8° curve, L. R. = 716.78 ft.	Tan preceding curve = 260.7 ft.
T. = 320.4 ft.	Tan between curves = 220.1 ft.
P. C. = 24 + 34.5	Tan 8° curve = 320.4 ft.
Length curve = 602.1 ft.	Total, = 801.2 ft.
P. T. = 30 + 36.6	tan 48° 10′ = 1.11713
Def. 100 ft. = 4° 00′	400 ft. × 1.11713 = 446.8 ft.
Def. 1 ft. = 2.4′	
Int. Ang. = 44° 30′	From intersection to intersection.
9° curve, R. R. = 637.27 ft.	Tan preceding curve = 278.5 ft.
T. = 260.7 ft.	Tan between curves = 378.3 ft.
P. C. = 17 + 20	Tan 9° curve = 260.7 ft.
Length curve = 494.4 ft.	Total, = 917.5 ft.
P. T. = 22 + 14.4	tan 44° 30′ = .98270
Def. 100 ft. = 4° 30′	400 ft. × .98270 = 393.1 ft.
Def. 1 ft. = 2.7′	

A B, towards the right, as the curve is to the right, and upon this perpendicular scale off the calculated tangent 790.7 ft., locating the point *E*. A line joining the points *C* and *E* will give the direction of the forward tangent. On the line *C E*, scale off from *C* the tangent distance, 440.7 ft., locating the point *F*, which is the P. T. of the first curve. From *A* and *F* as centers, with radii of 716.78 ft., the radius of an 8° curve, describe arcs intersecting at *G*. Then, from *G* as a center, with the same radius, describe a curve joining the points *A* and *F*. The curve *A F* is an 8° curve and tangent to the lines *A A'* and *F E* at the points *A* and *F*.

We find from the notes that the next curve is 6° R. Its P. C. is at Sta. 13 + 16, and its central angle is 44° 20′. We find its tangent distance is 389.2 ft. We next calculate the distance from the intersection point of the first curve to the intersection point of the second curve. The distance is composed of three parts; viz., the tangent of the preceding curve, which is 440.7 ft.; the intermediate tangent, i. e., from the P. T. of the preceding curve at Sta. 7 + 89.6 to the P. C. of the second or 6° curve at Sta. 13 + 16, a distance of 526.4 ft., and the tangent of the 6° curve, which is 389.2 ft., making a total distance of 1,356.3 ft. Produce the line *C E*, and scale off from *C* on that line a total distance of 1,356.3 ft., locating the point *H*, which is the intersection point of the second or 6° curve. Produce *C H* 400 ft. to *K* for a radius in laying off the central angle, 44° 20′ R., of the second curve. The tangent of 44° 20′ is .977, which, multiplied by 400, gives 390.8 ft. At *K* erect a perpendicular to *H K*, and upon it scale off the tangent 390.8 ft., locating the point *L*. The line joining *H* and *L* gives the direction of the forward tangent of the second curve. Next, from the intersection point *H*, scale off on both back and forward tangents the tangent distance 389.2 ft., locating the P. C. of the second curve at *M*, Sta. 13 + 16, and its P. T. at *N*, Sta. 20 + 54.9 Next, from *M* and *N* as centers, with a radius of 955.37 ft., the radius of a 6° curve, describe arcs intersecting at *O*. Then, from *O* as a center, with the same radius, describe a curve joining the points *M* and *N*. The curve *M N* is a 6°

curve and tangent to the lines $F\ H$ and $H\ L$ at the points of curve M and N.

The student will draw the tangent distances and the radii and tangents for laying off angles in dotted lines, as they are simply construction lines. The line of survey he will draw in a full, bold line, as shown in the plate. The intersection points and the points of curve and tangent are marked by small circles, the latter being more fully described by their station numbers. Dotted radial lines are drawn from the center of each curve to its P. C. and P. T. On one of these radial lines the length of the radius of the curve is written, and the amount of the central angle written within the radial lines. The student will need no further directions to enable him to plat the balance of the line and also the notes for Example 2, a plat of which is given in Fig. 2.

1364. Office Curves and Beam Compass.—Office curves are curves of different radii, whose principal object

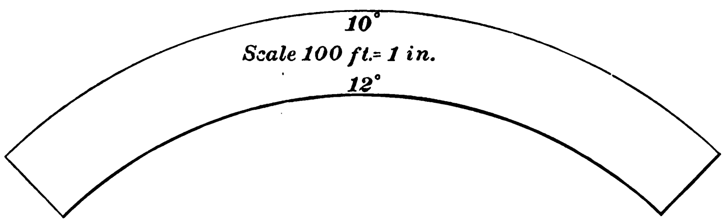


FIG. 336.

is to enable the engineer to readily select a curve which shall best fit the ground lying between tangents, as shown in the topographical map. They are commonly made of pasteboard, each piece containing arcs of two different radii, the degrees of curvature of which, together with the scale of each, being distinctly written, as shown in Fig. 336. A 10° curve to a scale of 100 feet to the inch will serve for a 5° curve to a scale of 200 feet to the inch, or a 2° 30′ curve to a scale of 400 feet to the inch. In the same way, a 12° curve to a scale of 100 feet to the inch will serve for a 6° curve to a scale of 200 feet to the inch, or a 3° curve to a

scale of 400 feet to the inch. Office curves are applied directly to the contour map upon which a grade line has been platted, and the curves fitted to ground and tangent. Compound curves are as readily fitted as simple curves. A satisfactory line being decided upon, the tangent distances are calculated and the curves struck with a compass.

When the radius is of considerable length, it is difficult to describe a true circle with the ordinary compass and lengthening bar.

An accurate substitute is found in the **beam compass**, which consists of two upright legs; one pointed and fixed at the center of the circle; the other leg carrying either pencil or pen, with which the circle is described. Both legs

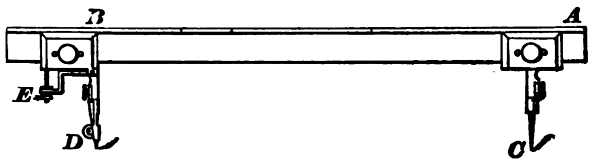


FIG. 337.

are clamped to a horizontal arm called a beam, which is lengthened or shortened to suit the radius. A cut of a beam compass is shown in Fig. 337. *A B* is the beam, to which is clamped the needle point at *C* and the pen or pencil at *D*. At *E* is a milled-headed screw, which gives slow movement to the pen or pencil at *D* and adjusts it to the required radius.

TOPOGRAPHICAL DRAWING.

1365. General Definition.—Topographical drawing consists of the representation of the different features of any portion of the earth's surface. The different features will comprise all its inequalities of surface, such as hills, hollows, streams, lakes, valleys, and plains; the location of towns, highways, canals, and railroads. Detailed topographical maps give individual dwellings, boundaries of fields, their owners, the character of the vegetation, etc.

1366. Systems.—There are three principal systems of representing topographical features, viz.:

1. By level contours or horizontal sections.
2. By lines of greatest slope perpendicular to contours.
3. By shades from vertical light.

1367. Ridge Lines and Valley Lines.—Ridge lines are the lines which divide the water falling upon them and from which it passes off on opposite sides. They are the lines of least slope when looking along them from above downwards, and the lines of greatest slope when looking along them from below upwards. They can be readily determined by the slope level. On these lines are found the projecting or protruding bends of the contour lines.

Valley lines are the reverse of *ridge lines*. They are indicated by the water courses which follow or occupy them. They are the lines of greatest slope when looked at from above and of least slope when looked at from below. On these lines are found all the receding or reentering points of the contour lines.

1368. Forms of Ground.—It will be found from a general examination of *any* surface that ground exists under one of the five following conditions, viz.:

1. Sloping *down* on *all sides*, i. e., a hill, as shown in Fig.

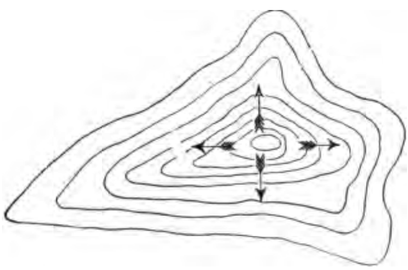


FIG. 338.

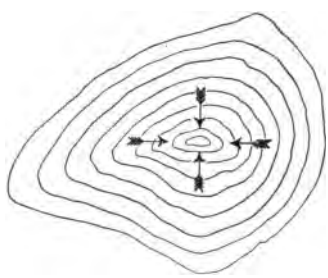


FIG. 339.

338, the direction in which water would flow being indicated by the arrows.

2. Sloping *up* on *all sides*, i. e., a hollow, as shown in Fig. 339.

3. Sloping *down* on *three* sides, i. e., shoulder or promontory; the end of a ridge or watershed line, as shown in Fig. 340.

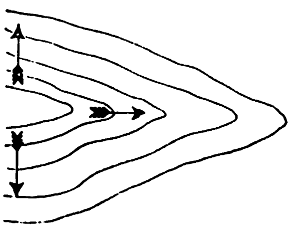


FIG. 340.

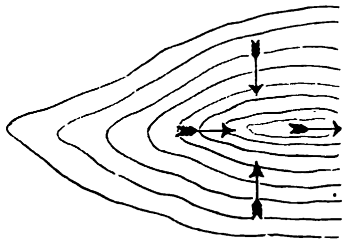


FIG. 341.

4. Sloping *up* on *three* sides and *down* on *one* side, i. e., a valley, as shown in Fig. 341.

5. Sloping *up* on *two* sides and *down* on *two* sides, alternately, called a saddle, and shown in Fig. 342.

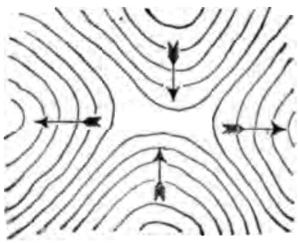


FIG. 342.

1369. Clear and Intelligible Maps.—No pains should be spared in making maps clear and intelligible. All water courses, whether occupied or dry, should be accurately sketched, and *gaps* should be left in the contour lines at suitable intervals, with the *elevation* of the contours written in them. Where time and cost are not to be considered, the lower sides of the contours may be hatched as though water were draining off them, and the valleys and low places tinted with a light shade of India ink.

Sometimes the spaces between the contour lines are tinted with India ink, increasing the tint as the depth increases.

Ground under water is commonly so represented. Beginning at low water-line, the space to the depth of 6 feet is covered with a dark shade of India ink; from 6 feet to 12 feet

with a lighter shade; from 12 feet to 18 feet with still lighter, and from 18 feet to 24 feet with lightest of all. Greater depths are marked in fathoms.

1370. Uses of Contours:

1. *To locate roads.*

2. *To obtain vertical sections—profiles.*

3. *To calculate excavation and embankment.*

In both railroad and highway location, the contour map is used in platting a grade line to which the final location should closely approximate. The paper location is then made, conforming as closely as possible to the grade line in the contour map, and from that location a final profile is platted.

When the contour map is to be used as a basis for the calculation of excavation and embankment, a hill or hollow is conceived to be divided into horizontal sections. The areas of the upper and lower bases of any section are then calculated and their average is multiplied by the altitude of the section, which gives the content of that section.

PLATE, TITLE: CONTOURS AND SLOPES.

1371. This plate contains three examples in *topographical drawing*. Each example affords practice in drawing shore lines. Fig. 1 is an example under the *first system* in which the topography is represented by *level contours*, and affords the student excellent practice in contour mapping. Figs. 2 and 3 are examples under the *second system* in which topography is represented by *lines of greatest slope or hatchings.*

First System—By Level Contours.—In Fig. 1 the situation is a steep hillside bordering upon a lake. The engineer before commencing the field work should examine the ground thoroughly in order that he may intelligently choose a method of work well suited to the situation. In the case in hand, the surface of the water in the lake is adopted as the datum plane.

It is a common and excellent practice to divide the area to be contoured into squares, the dimensions of which will depend upon the area to be treated and the degree of detail required in the work. Large areas are usually divided into squares containing 100 ft. on a side. The division lines serve as guides to those taking the levels. The intersections of the division lines being 100 ft. apart, they render the location of any intermediate point an easy task. These intersections are called stations, and are usually numbered consecutively or distinguished in some other way. In Fig. 1 the area is divided into squares 100 ft. on a side. *Base lines A X* and *A H* are first established where distant and well-defined targets may be set up and the lines carefully measured. The importance of an accurately measured base line, and of a distant fixed target can not be overestimated. The lines of division are determined by laying off lines at 90° to these bases, and are supposed to be parallel, a difficult thing to accomplish in rough country where short sights are frequent, and impossible if the initial angle of each line is not turned from the same backsight, and that a comparatively distant one. The base lines being established, the lines of division are carefully run. The vertical division lines, i. e., those parallel to general direction of the lake shore, are designated by the letters of the alphabet, the first being described as line *A*, the next as line *B*, the next as line *C*, and so on. The horizontal division lines are numbered consecutively, commencing with the bottom line, which is numbered 0, the next parallel to it 1, the next 2, and so on. The intersections of the division lines locate the succeeding stations on each line. This greatly simplifies the keeping of the notes, and enables the engineer to readily locate any point and briefly describe it. Thus, the starting point of line *A* is called line *A*, 0; the next intersection is called line *A*, 1; the next line *A*, 2, etc. The engineer determines the form of notes best suited to the situation. He will find a leveling rod 20 ft. in length of great assistance when working in a locality where changes in elevation are frequent and abrupt. The form of notes best adapted to the work in

hand is the following, the notes being a record of the levels which are taken at each intersection of the division lines:

LEVELS OF LINE *A*.

Station.	Rod Reading.	Height of Instrument.	Elevation.
B. M.	+ 8.80	56.05	47.25
0	7.20	.....	48.80
1	13.70	.....	42.30
T. P.	− 19.72	.....	36.33
	+ 4.20	40.53	.....
2	5.70	.....	34.80
3	14.80	.....	25.70
T. P.	− 18.63	.....	21.90
	+ 3.53	25.43	.....
4	7.10	.....	18.30
5	9.30	.....	16.10
T. P.	− 18.55	.....	6.88
	+ 3.22	10.10	.....
6	9.60	.....	0.50
6 + 05	.....	.....	Edge of Lake.

1372. The **contour map** is made as follows: First we draw the outlines of the given area, 1,100 ft. in length by 750 ft. in width, to a scale of 100 ft. to the inch. These boundaries are then divided into equal spaces of 100 ft. each, as shown in the engraving, and the lines of division drawn, the boundaries being drawn full and the division lines dotted. The vertical division lines, as before stated, are designated by the letters of the alphabet, and the horizontal lines by numerals.

From the level notes we find the elevations of the stations on lines *A* and *B*. These elevations we mark on the map at their proper stations, and then locate the contour lines as follows: Beginning with line *A*, we find that the elevation of Station 0 is 48.8 ft.; that of Station 1 is 42.3 ft.; hence,

the difference of elevation between these stations is 48.8 − 42.3 = 6.5 ft. The distance between these stations is 100 ft., and the rate of fall between Stations 0 and 1 is equal to $\frac{100}{6.5} =$ 15.4, which is called a descending slope of 1 to 15.4. The contours are 5 ft. apart, and, therefore, the elevations of each contour will be some multiple of 5 ft. Contour 45 ft. will come between Stations 0 and 1 of line *A*. As the elevation of Station 0 is 48.8 ft., we must, to reach contour 45, go

LEVELS OF LINE *B*.

Station.	Rod Reading.	Height of Instrument.	Elevation.
		10.10	
7 + 12	......	.....	Edge of Lake.
7	8.00	......	2.10
T. P.	− 1.24	......	8.86
	+ 19.84	28.70	......
6	8.30	......	20.40
T. P.	− 1.65	......	27.05
	+ 19.91	46.96	......
5	15.00	......	32.00
4	9.20	......	37.80
3	1.70	......	45.30
T. P.	− 2.21	......	44.75
	+ 18.88	63.63	......
2	6.90	......	56.70
T. P.	− 2.24	......	61.39
	+ 18.31	79.70	......
1	15.50	......	64.20
0	4.40	......	75.30

towards Station 1 far enough to descend an amount equal to 48.8 − 45.0 = 3.8 ft. As the rate of fall is 1 in 15.4, to fall 3.8 ft. we must go 15.4 × 3.8 = 58.5 ft., which brings us

to contour 45. This distance we scale off to a scale of 100 ft. to the inch, marking the point where contour 45 crosses line A by a small dot. The next two lower contours are 40 and 35. As the elevation of Station 1 is 42.3 and that of Station 2 is 34.8, both of these contour lines will cross the line between these stations. The total fall between Stations 1 and 2 is $42.3 - 34.8 = 7.5$ ft., and the rate of fall is $\frac{100}{7.5} = 13.3$. To reach contour 40 we must fall 2.3 ft. below Station 1, and the distance will be $2.3 \times 13.3 = 30.6$ ft. To reach contour 35 we must fall 5 ft. more, and the additional distance will be $5 \times 13.3 = 66.5$ ft. We accordingly locate those contours at 30.6 ft. and at $30.6 + 66.5 = 97.1$ ft. from Station 1. The difference of elevation between Stations 2 and 3 is $34.8 - 25.7 = 9.1$ ft., and equivalent to a descending slope of 1 to 11 between them. Contour 30 will come at $4.8 \times 11 = 52.8$ ft. from Station 2. The difference of elevation between Stations 3 and 4 is $25.7 - 18.3 = 7.4$ ft., which gives a descending slope of say 1 to 14. This is not the exact rate of slope, but where decimal fractions are small and slopes easy the fractions may be ignored, as they will not to a perceptible degree affect the accuracy of the work. Contour 25 will come at $14 \times .7 = 9.8$ ft. from Station 3, and contour 20 at a point 70 ft. farther, or at say 80 ft. from Station 3. The difference of elevation between Stations 4 and 5 is $18.3 - 16.1 = 2.2$, but no contour line passes between these points. The difference of elevation between Stations 5 and 6 is $16.1 - .5 = 15.6$, which gives a slope of 1 to 6.4. This brings contour 15 at 7 ft., contour 10 at 39 ft., and contour 5 at 71 ft. from Station 5.

1373. The usual custom is to *work up the notes*, as it is called, before commencing the platting of the contours, and when a considerable portion of the ground has been covered, plat them, and thus avoid the delay incurred by frequent changes of work. Each engineer decides upon that form of notes best suited to the character of the work in hand. The following is a clear and simple form of notes

in which is given the location and elevation of the contours on line *B* and on the cross-section lines between lines *A* and *B*:

Line *B*.	Contours Between Lines *A* and *B*.
Sta. 0 to 1.	from *A 0* to *B 0*.
0 + 3 to contour 75	5 ft. to contour 50
0 + 48 to contour 70	24 ft. to contour 55
0 + 93 to contour 65	43 ft. to contour 60
	62 ft. to contour 65
	81 ft. to contour 70
	97 ft. to contour 75
Sta. 1 to 2.	*A 1* to *B 1*.
1 + 56 to contour 60	12 ft. to contour 45
	34 ft. to contour 50
	57 ft. to contour 55
	79 ft. to contour 60
Sta. 2 to 3.	*A 2* to *B 2*.
2 + 15 to contour 55	1 ft. to contour 35
2 + 59 to contour 50	23 ft. to contour 40
	46 ft. to contour 45
	68 ft. to contour 50
	91 ft. to contour 55
Sta. 3 to 4.	*A 3* to *B 3*.
3 + 04 to contour 45	21 ft. to contour 30
3 + 70 to contour 40	46 ft. to contour 35
	71 ft. to contour 40
	96 ft. to contour 45

Line *B*.	Contours Between Lines *A* and *B*.
Sta. 4 to 5. 4 + 48 to contour 35	*A 4* to *B 4*. 9 ft. to contour 20 34 ft. to contour 25 59 ft. to contour 30 84 ft. to contour 35
Sta. 5 to 6. 5 + 17 to contour 30 5 + 60 to contour 25	*A 5* to *B 5*. 24 ft. to contour 20 55 ft. to contour 25 86 ft. to contour 30
Sta. 6 to 7. 6 + 02 to contour 20 6 + 29 to contour 15 6 + 56 to contour 10 6 + 83 to contour 5	*A 6* to *B 6*. 22 ft. to contour 5 47 ft. to contour 10 72 ft. to contour 15 97 ft. to contour 20
Sta. 7. 7 + 12 to contour 0, at edge of lake.	*A 7* to *B 7*. 95 ft. to contour 0, at edge of lake.

1374. The student having worked up these notes can, with a little practice, plat them rapidly, using a decimal scale. A small offset scale is very convenient in locating contours. The examples given in working up notes will enable the student to similarly treat the others. He should be systematic in his calculations and platting, completing all the calculations on one line before commencing another, and do likewise in his platting. Otherwise, confusion is sure to follow.

The elevations of the ground at the intersections of the division lines are given in the engraving. This is done for the convenience and assistance of the student. In regular office work the elevations of these points are taken from the level book, and the only elevations given in the map are those of the contours, which are written in gaps left in the contours for that purpose.

These elevations should be distinctly written, and, unless the slopes are very steep, bringing the contours very close together, the elevations should be written successively one above the other. In drawing the shore line, avoid the drawing of straight, regular lines. All shore lines, and especially those of lakes, are very irregular. A heavy line is first drawn outlining the shore, then a lighter one, at a small distance from, and parallel to, the first; then another line, at a greater distance from the second than the second is from the first; and so on until the shore line is clearly defined.

The contours themselves are to be drawn free-hand with an ordinary writing pen.

1375. Second System—By Lines of Greatest Slope.—Their direction is that which water would take in running off them. They are drawn *perpendicular* to the *contour lines*, and are called *hatchings*. An example of this system is shown in Fig. 343.

In sketching topography by this system, the topographer should hold the book directly in front of him so as to correspond with his position on the ground, drawing the lines *towards him*. If at the top of a hill, begin by drawing the lines from the bottom, and *vice versa*. To guide the hatchings, he should lightly sketch in the contour lines. Hatchings must be drawn *truly perpendicular* to the contour lines. Where the contour lines curve sharply, it is often well to draw in hatchings at considerable intervals as a guide to the main body of those drawn afterwards. Hatchings in adjoining rows should *not be continuous*, but so drawn as to *break joints*. They must not overlap, and should be drawn in

slightly wavy lines. In drawing a hill where the slopes are steep and irregular, it is often well to draw auxiliary contours.

An example of this system is given in Fig. 2 of Plate, Title: Contours and Slopes, which represents an abrupt promontory. Its base marks the channel of a river. The ground on the opposite side of the river is generally level with occasional undulations. The degree of the slope is indicated by the spacing of the contours and the corresponding lengths and number of hatchings. The more abrupt the slope the closer together the contours and hatchings.

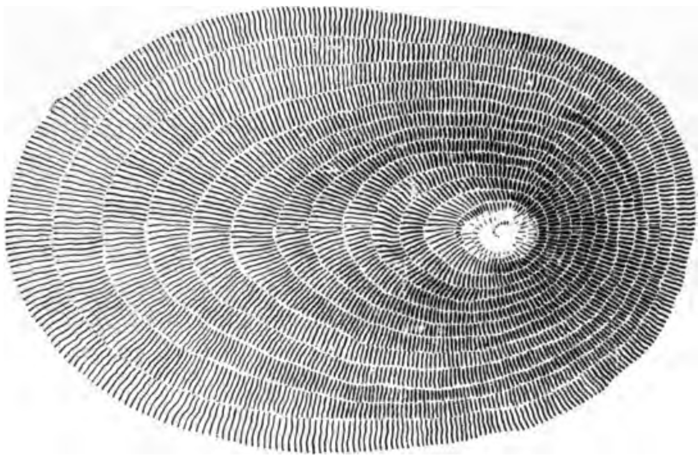


FIG. 343.

The preliminary work necessary for such a topographical map is as follows: A traverse or meander line is run, marking the windings of the stream. Having platted this meander line, the topographer takes his book containing the sketch, and from the promontory itself sketches in the main features of the surface. A hand level is of great service in determining relative elevations. From these notes the final map is made up, the work being done in the office. Fine topographical drafting should not be attempted in camp. The facilities of a well-equipped office are necessary to rapid and satisfactory work. The student is not expected

to reproduce the *exact outline of the figure*, but it is expected that his work will show a proper understanding of the subject. Having drawn the outline of the river, he should draw in the contours in light pencil lines, spacing them to conform to the different slopes. It will be evident to the student that within the space represented by Fig. 2 the surface of the river at *C* and *D* will be practically the same. Hence, if the distance from the summit *A* to the river at *E* is but half the distance from *A* to *F*, the slope *A E* must be twice as abrupt as the slope *A F*. Hence, the contours which mark equal heights will be twice as far apart on the slope *A F* as on the slope *A E*. He should draw all the contours, outlining the summits at *A* and *B*, before commencing the hatchings. The short hatchings on either side of the river mark its banks. On the promontory side they are shorter than on the opposite side, as the former has the more abrupt banks. Fig. 3 of the same plate represents an irregular and abrupt sea coast. The survey for such an area would embrace a traverse of the entire shore line—of the island as well as the mainland. This traverse line should be used as a base line for auxiliary traverse lines, by means of which the summits *A*, *B*, *C*, *D*, and *E*, and any other important objects could be located. The heights of these summits could be determined either by triangulation or by the aneroid barometer. With this information as a basis, the shore line is located, the contours sketched in, and the hatchings drawn. As in the case of Fig. 2, the student is not expected to produce a *literal copy*, but to show his proficiency by furnishing a clear and finished drawing.

Hatchings should have their thickness and distance apart proportional to the steepness of the slope. The lines are made heavier as the slope is steeper, being fine for gentle slopes, and for very steep slopes the blank spaces are but half the breadth of the lines.

1376. Third System—By Shades from Vertical Light.—The steeper the slope the less light it receives. In practice, the difference in color is much exaggerated.

Various governments have prepared tables establishing the ratio of color to different slopes. The shading is applied in various ways. A rapid method, and a sufficiently accurate one for many kinds of work, is to sketch in the contours and then apply the shading in the form of India ink. Each varying tint is applied with its particular brush, care being taken not to allow any tint to dry before the succeeding tint is applied. By this means the tints are blended, giving a smooth and finished effect to the work. The tints are made light for gentle slopes and dark for steep slopes, a slope of 60° being black and one of 30° being midway between black and white, and so on.

1377. Shades by Contour Lines.—This is accomplished by interpolating additional contour lines between the regular contours. Confusion is likely to result from this method, especially where the slopes are steep, as the numerous contours are liable to run together or be confused with roads or boundaries.

CONVENTIONAL SIGNS.

1378. Sand, Rock, Etc.—Sand is represented by fine dots made by the point of a pen; gravel by coarser dots. Rocks are represented by angular, irregular masses, as would appear when seen from above and drawn in their proper places.

1379. Signs for Vegetation.—Woods are represented by scalloped circles, irregularly placed, closer or

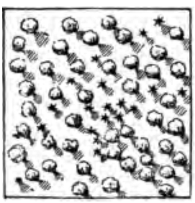


FIG. 344.

FIG. 345.

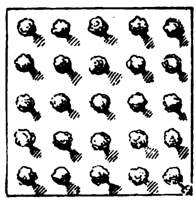


FIG. 346.

farther apart, according as the forest is dense or open. Their shadows are drawn on their lower right-hand sides, as shown in Fig. 344. Sometimes trees are drawn in elevation,

as shown in Fig. 345. This method is not admissible according to the laws of projection, but it is very effective. and deciduous trees are more readily distinguished from evergreen by this method than by that shown in Fig. 344, where deciduous trees are represented by scalloped circles and evergreens by stars.

Orchards are represented by trees in regular rows, as shown in Fig. 346.

Bushes are drawn like trees, but in smaller figures. Fig. 347 represents bushes and trees intermingled.


FIG. 347.

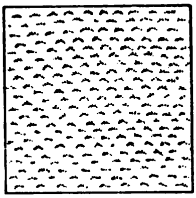


FIG. 348.

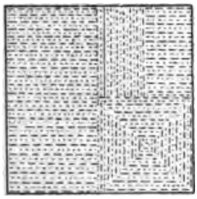


FIG. 349.

Grass land is represented by irregular groups of short diverging lines, as shown in Fig. 348.


FIG. 350.

Uncultivated land is shown by interspersing the signs of sand, grass, bushes, etc.; cultivated land by parallel rows of broken lines, as in Fig. 349.

Swamp land is represented by grass, bushes, and water, as in Fig. 350.

1380. Shore Lines.—The sea-shore is represented by a line following all its windings and indentations. A short

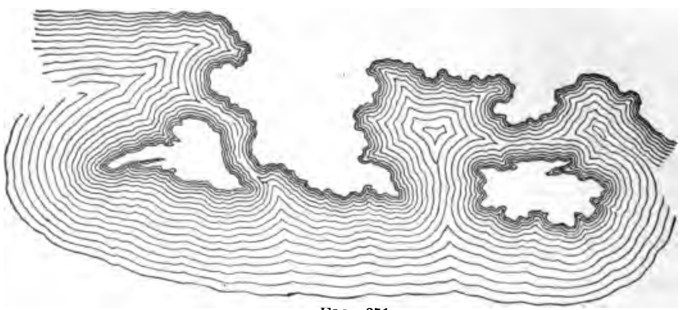


FIG. 351.

distance from the shore line, a parallel line is drawn, and a little further removed a second parallel, and so on, as in Fig. 351.

An abrupt and rocky shore is shown in Fig. 352. The irregular dotted surfaces surrounded by shore lines represent

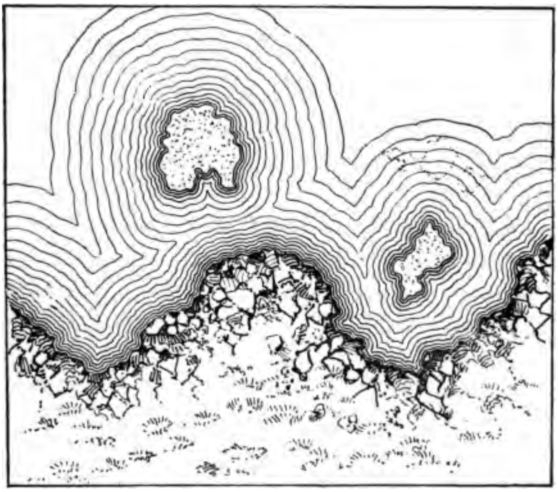


FIG. 352.

sand bars. The dotted outlines beyond the shore lines represent either shoals or sunken rocks.

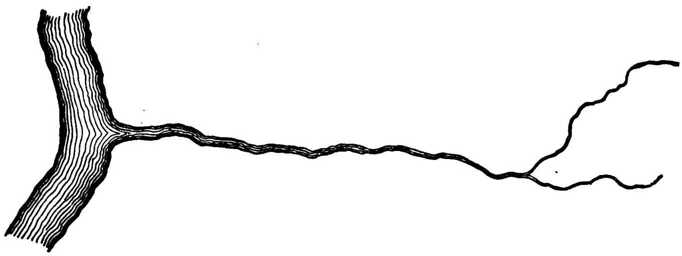


FIG. 353.

Rivers have their shore lines treated in the same manner as the sea-shore, as shown in Fig. 353.

Large brooks are represented by two parallel lines; small brooks by a single line.

1381. Grounds and Gardens.—Grounds and gardens are represented in plan as follows: The grounds, by boundaries of property and street lines; the house and other buildings, by their ground plan, and drives, walks, lawn, shrubbery, and trees, by either outlines or conventional signs. The gardens by rectangular beds and other forms of arrangement.

PLATE, TITLE: TOPOGRAPHICAL MAPS.

1382. Fig. 1 of this plate illustrates the use of conventional signs in practical landscape gardening, affording the student some knowledge of how a given area may be disposed so as to combine artistic arrangement with practical utility. It contains a plat of a house, grounds, and gardens drawn to a scale of 50 feet to the inch. All necessary dimensions are given for an accurate reproduction of the work. The student should first carefully study the outlines, and accurately determine their dimensions, after which the details will be a simple matter.

In drawing Fig. 1, first lay out the boundaries of the plat of ground, 375 ft. front by 515 ft. deep.

The width of the street fronting the lot is 60 ft. From the front corners of the lot A and A', measure $A\,B$ and $A'\,B'$, each $17\frac{1}{2}$ ft., locating the center line of the carriage drive. From B and B' measure 100 ft., locating the centers C and C'. From these centers with equal radii $C\,B$ and $C'\,B'$ describe equal arcs $B\,D$ and $B'\,D'$ containing 30°. Produce the radii $C\,D$ and $C'\,D'$ until they intersect at E. If the work has been correctly done, E will be equidistant from the corners A and A'. Through E draw a line $E\,E'$ at right angles to the line $A\,A'$. This line will divide the lot into two equal parts and form the main base line for the location of points in the plat. With the radius $E\,D$ 181 ft. in length describe the arc $D\,D'$, completing the center line of the front carriage drive. The drive is 15 ft. in width. The inner boundary is described by simply reducing the length of the radius $7\frac{1}{2}$ ft., and the outer boundary by increasing the length an equal amount. We next measure

from the street corner A on the left boundary the distance $A F = 300$ ft., and at F draw $F F'$ perpendicular to $A F$. At some point G of the main base line $E E'$, draw $G G'$ perpendicular to $E E'$ and 95 ft. in length. At G', the extremity of this perpendicular, draw a line $H H'$ perpendicular to $G G'$ intersecting $F F'$ at I, which point is the center of an elliptical curve in the carriage drive. The major axis $K K'$ of this ellipse is 85 ft., and the minor axis $L L'$ is 66 ft. in length. This ellipse the student will draw according to the method described in the section on Mechanical Drawing. Having drawn the ellipse, the student will readily draw the border lines of the drive by increasing or reducing the lengths of the various radii.

Draw both outer and inner boundaries of the ellipse in pencil so as to form closed figures. From some point M of the street line draw $M M'$ 213 ft. in length and parallel to $E E'$. Through M' draw $M' M''$, perpendicular to $E E'$. From $E E'$ and $M' M''$ locate the house from dimensions given. From some point N of $E E'$, draw $N N'$ 110 ft. in length and perpendicular to $E E'$. At N' draw in both directions an indefinite line perpendicular to $N N'$. At some point O of the line $E E'$ erect a perpendicular $O O'$ 35 ft. in length, and through O' draw an indefinite line parallel to $E E'$. From a point O' of this line with a radius of 100 ft. describe an indefinite arc $P P'$, being careful that the extremity P shall be in a tangent to the center line at the carriage driveway. Then, from some point Q, found by trial, with a radius of 50 ft., describe an arc $P' N'$ which shall be tangent to the straight line through N' and the arc $P P'$. In a similar manner find centers at the points R, S, T, and U, from which with the given radii describe arcs forming the center line of the carriage driveway. Having located the center line complete, the boundaries are put in as previously directed, being careful to unite the various curves with smooth, even lines. The arc described from the center U must be tangent to the ellipse and to the center line $V V'$, which is $15\frac{1}{2}$ ft. distant from the boundary of the lot. The stable lot is 75 ft. square. The buildings may be readily

located from figures given in the drawing. The kitchen garden extends from the rear boundary of the lot 150 ft. towards the street, and from the right-hand boundary to the driveway and stable yard. It is divided into rectangular plots, the various sizes being suited to the character of the vegetables grown. All dimensions necessary for a reproduction of the drawing are fully given.

1383. Fig. 2 shows a portion of a town, together with its connections with railroad and canal. The student will make the drawing to a scale of 200 feet to the inch.

Before commencing this plate the student will note that the magnetic meridian is parallel to the right and left borders of the plate. At 250 ft. from the S W corner of the plat we locate a plug, which is the starting point for the traverse of the river. Call this plug Sta. 1. Thence, run N 22° 30′ E 734 ft. to Sta. 2; thence, N 60° 30′ E 576 ft. to Sta. 3, the center of Main street; thence, N 68° 15′ E 430 ft. to Sta. 4. At 100 ft. from the starting point the river is 30 ft. to right; at Sta. 2 it is 70 ft. R.; at Sta. 3, 40 ft. R.; at Sta. 4. 44 ft. R. The river has an average width of 400 ft. The student will draw in the shore line from the offsets given above, giving it the same contour as shown in the plate. The opposite shore the student will locate by offsets, averaging 400 feet each. Again starting at Sta. 3 of the river traverse, a line is run N 16° W along the center of Main street, producing the line backwards from Sta. 3 across the river and beyond to the boundary of the plat. The several lines of survey will be used as base lines for the location of streets, railroad tracks, canal, and all objects included in the map. The starting point of each line of survey is numbered zero, and all lineal base-line measurements are referred to the starting or zero points. Distances measured on the base line are expressed in stations of 100 ft. each, and offsets are given in full. Calling Sta. 3 of the river traverse 0, we measure northward to Sta. 0 + 90, the north end of the river and canal bridge. The wing walls of the abutments diverge at an angle of 30°. At Sta. 4 + 93 is the center of the track

of the P. & N. R. R., the bearing of which is N 73° 30′ E.

At Sta. 5 + 68 is the center of Putnam street, the bearing of which is N 73° 30′ E. At Station 11 + 68 is the center of Randolph street, the bearing of which is N 73° 30′ E. Produce the center lines of both Putnam and Randolph streets until they intersect the boundaries of the plat. Main street is 60 feet in width, and Putnam and Randolph streets are each 50 feet in width. Draw parallels to the center lines of these streets, locating the proper boundaries as shown in the plat. From the intersection of the center line of Main with that of Putnam street, measure eastward on the center line of Putnam street 450 ft. to the center of Tyler street, the bearing of which is N 3° 45′ W. Produce the center line of Tyler street northward until it intersects the north boundary of the plat. On the N E corner of Main and Randolph streets is a hotel fronting 110 ft. on Main and 100 feet on Randolph streets. The hotel has a depth of 60 feet from each frontage. On the S W corner of Main and Randolph streets is the postoffice, fronting 60 ft. on Main street and 40 ft. on Randolph street. Returning to the starting point, viz., Sta. 3 of the river traverse, and running southward on the center line of Main street, at Sta. 0 + 34 is the center of the shore pier, 10 ft. by 40 ft.; at Sta. 2 + 34 is the center of the channel pier, 12 ft. by 40 feet, and at Sta. 4 + 34 is the south end of the bridge. The bridge is 30 feet wide. The wing walls of the south abutment also diverge at an angle of 30°. The south approach is 40 ft. in width and 200 ft. in length. Beyond the approach the street has the full width of 60 feet.

At 100 ft. east of the S W corner of the plat is the center line of the S. & B. R. R., which has a double track, the track centers being spaced 13 ft. apart. The bearing of this tangent is N 15° 15′ E, and the given point is numbered Sta. 0. At Sta. 5 is the center of the towing path of the C. & O. canal, the bearing of which is N 54° 30′ E. At Sta. 9 + 44.1 is the P. C. of a 6° curve L. for 30°. The student will produce the center line to Sta. 12, which is the

point of intersection for the curve, laying off the tangent distance of 255.9 ft. Draw the center line of each track, spacing them 6.5 ft. from the main center line. Having located the center of the 6° curve, the parallel curves are struck with a compass, increasing the radius 6.5 ft. for the outer curve and diminishing it the same amount for the inner curve. North of Putnam St. the right of way of the S. & B. R. R. is 100 ft., 50 ft. each side of the main center line. Parallel to this center line on each side of the railroad is a street 40 ft. in width. Produce the center line of the east track of the S. & B. R. R. until it intersects the center line at the P. & N. R. R. The intersection angle is 57° 30′. Unite these tangents by a 10° curve. At Sta. 6 + 63 of the S. & B. R. R. west track, is the P. C. of a 16° curve L. for 27°, which we call track *A*.

At 40 ft. from the P. T. of this curve is the center of a turntable, the diameter of which is 60 ft. From the circumference of the turntable to the inner wall of the roundhouse is 60 ft. The right-hand end wall of the roundhouse faces on a radial line from the center of the turntable, which line makes an angle of 30° 30′ with the tangent of the turnout curve. The left-hand end wall is similarly situated, making an angle of 91° 30′ with the tangent of the turnout curve. The depth of the stalls is 70 ft. The tracks at the inside wall line are spaced 15-ft. centers. From the center of the outside track to outside of end walls is 10 ft. At Sta. 8 + 92 of the west track is the P. C. of a 16° turnout curve, to left, for 30° 10′. This we call track *B*. The P. T. is on the line of the south end wall of a car shop. The side walls of the car shop are parallel to the tangent of the curve. The east wall is 15 ft. from the center line of the tangent and the west wall 50 ft., giving a total width of 65 ft. The length of the car shop is 200 ft. At the northwest corner of the car shop is an engine and boiler house 40 ft. square.

On the north side of Putnam street is a foundry, fronting 120 ft. on Putnam street and 175 ft. on Foundry street, the building having a depth of 50 ft. from both frontages. The east side of the building is parallel to the tangent of the

turnout curve leading to the car shop, and 10 ft. from it. At Sta. 11 + 55, as measured on the produced tangent of the S. & B. R. R. is the south end of the platform of the R. R. station. At Sta. 12 is the south end of the station proper. The station is 67 ft. long, as measured on this tangent. The outer edge of the platform is 8 ft. from the center line of the adjacent tracks. The platform is 10 ft. wide and extends on all sides of the station, the curved walls of which are parallel to the railroad tracks.

At Sta. 8 of the S. & B. R. R. is the P. C. of a 16° turnout curve R., which leads from the east track, containing 39° 50′, and called track *C*. A tannery, 300 ft. in length by 90 ft. in width, extends from the P. T. of this curve, parallel to and 20 ft. to the right of the center line of the tangent. A bark shed of the full width of the tannery forms a continuation of the tannery and extends to Main street. A platform 10 ft. in width extends the entire length of the tannery, between it and the tracks. At the southwest corner of the tannery is an engine and boiler house 50 by 80 ft. At 60 ft. from the P. C. of track *C* and tangent to that curve, track *D* commences.

At 54 ft. from the commencement of track *D* is the P. C. of a 23° curve R. for 28° 38′, and called track *E*, which terminates in a tangent parallel to the tangent of track *C*, and spaced 12 ft. from it. At 364 ft. from the P. T. of track *E* is the west end of a coal chute. The south side of the chute is 8 ft. from the center of the track; the north side is 22 ft. from the center of the track, which gives the building a total width of 30 ft. It extends in length to Main street. At 257 ft. from the commencement of track *D* is the P. C. of a 16° curve R. for 31°, and called track *F*. At 8 ft. to the right and parallel to the tangent of this curve is a freight depot, extending from the P. T. of the curve and 200 ft. long by 35 ft. wide. On the south side the freight station is a platform 10 ft. wide, extending its entire length. At 312 ft. from the commencement of track *D* is the P. C. of a 23° curve R. for 31°, the tangent of which is parallel to track *F*, their center lines being spaced 12 ft.

Between Sta. $5 + 78$ of the S. & B. R. R. west track, and Sta. $7 + 51$, east track, is a cross-over track, which we call track *G*. This consists of two turnout curves, one commencing at each of the given stations and intersecting on the main center line. The curve commencing at Sta. $5 + 78$ is a $9° 30'$ curve R.; the curve commencing at Sta. $7 + 51$ is also a $9° 30'$ curve R., but described in the opposite direction. If carefully drawn, these curves will intersect on the main center line. Between Sta. $14 + 44.1$, east track, and Sta. $16 + 17.1$, west track, is another cross-over, which we call track *H*. The curves are both $9° 30'$, described in opposite directions, as in the preceding case.

Starting at Sta. 5 of the S. & B. R. R., which is directly over the center line of the towpath of the C. & O. canal, the bearing of which is N $54° 30'$ E, we measure northeastward along the center line of the towpath 706 ft. to the P. C. of a $12°$ R. for $12°$. Produce the back and forward tangents of this curve until they intersect the borders of the plat. The towpath is 12 ft. wide and the canal 40 ft. wide. The canal makes the same curve as the towpath, the arcs being struck from the common center. The student will draw the boundaries of the canal and towpath in ink, but need not ink in the center line of the towpath. The north abutment of the Main St. canal and river bridge is 4 ft. from the boundary of the canal. At 443 ft. from our starting point on the towpath is the west end of a canal dock, which consists of a widening of the canal in which boats are moored while their cargoes are being discharged. This dock is 240 ft. long and 20 ft. wide, providing berths for four boats. At 120 feet from the west end of the dock is the west end of a coal chute, the south side of which is parallel to and 20 ft. from the dock. The coal chute is 40 by 200 ft. The railroad bridge over the canal is 30 ft. wide. The south abutment is placed 12 ft. and the north abutment 6 ft. from the canal, both abutments being parallel to the canal. The outer faces of the wing walls of these abutments are parallel to and 10 ft. from the center line of the nearest track.

PLATE, TITLE: MAP OF A VILLAGE.

1384. This plate represents a topographical map of a village. In making a survey of this description the engineer will select for a starting point some well-defined landmark; but as there are a score of points to choose from, the choice will depend upon the judgment of the engineer. The intersection of the center lines of two highways or the head block of a railroad switch are excellent points from which to commence a survey. The center lines of highways and railroads are the base lines from which the minor details, such as houses and other buildings are located. The quickest and best method of locating a building is to set a temporary plug on the base line near the building. Set up the transit at this point and measure the angles between the base line and two consecutive angles of the building, measuring the distances from the plug to the angles of the building. These angles and distances will locate one side of the building. A small free-hand sketch is then made, giving the base line, the station of the plug, or its distance from some known point, and the angles and distances to the side of the building. The remaining sides of the building are added to the sketch and their several lengths measured in consecutive order and marked on the sketch. These notes are quickly made and as quickly platted.

Sketches are of the greatest value in taking topographical notes. They can be made in less than half the time required for a full description, and are always more intelligible to the draftsman. Each surveyor has his individual methods, both in order of work and form of notes, and often one will consume twice as much time as another in performing the same work; but expedition is of no value if had at the cost of accuracy.

In this map all the conventional signs suited to an area of such magnitude are employed. The student will draw the map to a scale of 200 feet to the inch. The magnetic meridian is parallel to the right and left borders of the plate, the north point being at the top of the map. The center lines of the highways are given, together with their mag-

netic bearings, widths, and distances between the angles made by the center line. The center line of the railroad is represented by a heavy, full line, and the boundaries of the right of way, which is 100 feet in width, are represented by light full lines. The magnetic bearings of the tangents are given and the stations of the points of curve and tangent from which the lengths of the tangents are found by subtracting the station of the P. T. of one curve from the P. C. of the succeeding curve. The curves, instead of being run in from intersections of tangents, are platted as follows:

The location of the first tangent in the map being given by references to the boundary lines of the map, and the P. C. of the first curve denoted by its station, a perpendicular is erected to the given tangent, and upon it the length of the radius of the required curve is laid off to the given scale. Then, from the given center the curve is struck with a compass, being careful that the arc so struck shall contain as many degrees as the central angle of the curve, the central angle of the curve being laid off with a protractor. The intersection of the second radius with the arc will be the P. T. of the following tangent. A perpendicular is then erected to the second radius and tangent to the arc at the given intersection. The P. C. of the next curve being given, its length is readily found by subtraction. The borders of the lake are located by offsets.

The student is not expected to exactly duplicate the topography, but give the same general effect. All boundaries whose magnetic bearings are given and the location of all buildings he must faithfully repeat in his drawing.

1385. Starting at the northwest corner *K* of the map we measure eastward along the north boundary 700 ft. to *L*, the center of the S. & L. R. R., the bearing of which at that point is S 7° 45′ E. At 310 feet from this point is the P. C. of an 8° curve R., which we call Sta. 40 + 60. The central angle of this curve is 25°, and its length 312.5 ft. The station of the P. T. we find by adding the length of the

curve to the station of the P. C., giving 43 + 72.5 for the P. T. of the curve. The bearing of the forward tangent is S 17° 15′ W and its length 400 ft., making the station of the next P. C. 47 + 72.5. This curve is 9° R. and its central angle is 15°. Its length is, therefore, 166.7 ft., and the station of the P. T. 49 + 39.2. The bearing of the forward tangent is S 32° 15′ W, found by adding the central angle of 15° to the bearing of the preceding tangent. The length of the forward tangent is 610 ft. to Sta. 55 + 49.2, which is the P. C. of a 6° curve *L*. The curve is continued to the south boundary of the map.

The switch extending to the ice houses along the shore of the lake is located as follows:

Scale off from the northwest corner *K* of the map, along the north boundary 790 ft., eastward to the point *M*. From this point as a center, lay off with a protractor to the right of the north boundary an angle of 32° 30′. The bearing of this line is S 57° 30′ E. Scale 47 ft. on this line from the point in the boundary where the angle is turned. This will locate the P. C. of a 16° curve R., the station of which is 3 + 04.7. The central angle of this curve is 62° 05′, and the station at the P. T. 6 + 92.7. The bearing of the forward tangent is S 4° 35′ W. The next curve is 10° R. Its P. C. is at Sta. 10 + 93.7, and its central angle is 9° 40′, which brings the P. T. at Sta. 11 + 89.4. The bearing of the forward tangent is S 14° 15′ W. The next curve is also 10° R. Its P. C. is at Sta. 15 + 49.4, and its central angle 27° 30′, which brings the P. T. at Sta. 18 + 24.4. The bearing of the forward tangent is S 41° 45′ W. The last curve is 10° L. Its P. C. is at Sta. 24 + 24.4, and its central angle is 27° 10′, which brings the end of the line at Sta. 26 + 96.1.

With a protractor lay off from the P. C. of the 16° curve of the ice switch, a *central angle* of 18°. Draw a radius including this angle and at its extremity draw a tangent to the curve, with bearing of S 39° 30′ E. This point of tangent is the starting point of a switch leading to a coal chute. This point we call Sta. 0. At Sta. 0 + 65 of this track is the P. C. of an 18° curve R. for 36°, bringing the P. T. at Sta.

2 + 65. At this point the track enters a coal chute 50 ft. long by 30 ft. wide. The center line of the track is parallel to the sides of the chute and spaced 7 ft. from the west side. At 120 ft. from the starting point of the S. & L. R. R. is the north end of platform of a railroad station, and at 210 ft. from that point is the south end of the platform. The edge of this platform is spaced 6 ft. from the center line of the railroad track. The platform is 46 ft. in width at the north end and 50 ft. in width at the south end. The center line of a road 40 ft. wide commences at the middle point of the south end of the railroad station platform, and extends in the direction S 48° 30′ E 500 ft., where it intersects with the center line of the Scranton turnpike, the bearing of which is S 21° 30′ W. Call this point of intersection *A*.

Starting from intersection *A*, the traverse of the center line of the turnpike is as follows: S 21° 30′ W 310 ft.; thence, S 58° 30′ E 80 ft. to the west end of a bridge 20 ft. wide; thence, by same course 40 ft. to east end of bridge; thence, by same course 80 ft. to an intersection with center line of Andrews lane. Call this point of intersection *B*. Thence, S 11° 30′ W 300 ft. to intersection with center line of Waverly road. Call this point of intersection *C*. Thence, by same course 300 ft.; thence, S 8° 30′ E 250 ft.; thence, S 27° E 345 ft. to north end of a stone bridge 20 ft. wide; thence, by same course 30 ft. to south end of stone bridge; thence, by same course 125 ft. to an intersection with the center line of Newton road, the direction of which is N 63° E and width 40 ft. Call this intersection point *D*. From intersection *D* the turnpike extends in the direction N 83° E 400 ft., thence, S 76° E 325 ft.; thence, S 46° E to the south boundary of the map. The width of this turnpike is 50 ft.

Next we measure from the northwest corner *K* of the map, southward along the west boundary 344 ft. to the center *N* of the Benton road. From thence we measure along the center line of the road, N 80° 15′ E 356 ft.; thence, S 69° 45′ E 350 ft.; thence, S 89° 45′ E 45 ft. to west end of a culvert 20 ft. in width; thence, by same course, 50 ft. to

east end of culvert; thence, by same course, crossing the ice switch and road leading to the railroad station and continuing to an intersection with the Scranton turnpike, which is the terminus of the Benton road. Call this point of intersection *E*.

Starting at intersection *C*, we follow the center line of the Waverly road as follows: S 55° 15′ E 197 ft. to its intersection with the center line of Lenox lane. This point of intersection we call *F*. Thence, N 74° 45′ E 500 ft.; thence, S 85° 15′ E, intersecting the old Scranton and Montrose turnpike and extending by the same course to the east boundary of the map.

Returning to the point *F*, the intersection of the center line of the Waverly road with Lenox lane, we prolong the line *C F* from *F*, a distance of 290 ft. This forms the center line of Lenox lane, and intersects with the center line of Henderson lane. These intersecting center lines form an angle of 90° with each other, making the course of Henderson lane N 34° 45′ E. Produce the center line of this lane in both directions, intersecting on the south with the Scranton turnpike, and on the north with the Waverly road. The widths of the Waverly road and Lenox and Henderson lanes are each 40 ft. Commencing at the point *B*, where the Scranton turnpike intersects the center line of Andrews lane, we follow the center line of that lane in the direction N 31° 30′ E 300 ft. to an intersection with the center line of a private lane leading in the direction S 85° 30′ E 200 ft., where it turns at right angles, 40 ft. to the right and 75 ft. to the left. Continuing along the center line of Andrews lane by the same course 100 ft., we change the direction, running N 11° 30′ E, intersecting with Hall road. The width of Andrews lane is 30 ft.

Starting from the southeast corner *O* of the map, we measure westward along the south boundary 320 ft. to the center *P* of the old Scranton and Montrose turnpike. From this point we follow the center line of the turnpike as follows: N 27° 45′ W 440 ft.; thence, N 7° 45′ W 330 ft.; thence, N 2° 15′ E 1,280 ft., intersecting the Waverly and Hall

roads. The latter intersection makes the eastern limit of Hall road. Thence, N 5° 45′ W to the north boundary of the map. The width of this turnpike is 50 ft. Returning to point *E*, the terminus of the Benton and Hall roads, we follow the center line of Hall road S 89° 45′ E 165 ft. to the west end of a bridge 20 ft. wide; thence, by same course, 30 ft. to east end of bridge; thence, by same course, 400 ft. to an intersection with the center line of Prospect road, which extends in the direction N 40° 15′ E to the north boundary of the map. Call this point of intersection *G*. From the point *G* the center line of Hall road extends in the same direction, viz., S 89° 45′ E to its intersection with the center line of the old Scranton and Montrose turnpike. Call this intersection point *H*. The widths of the Hall and Prospect roads are 40 feet.

The right of way of the S. & L. R. R. is 100 ft. in width, 50 ft. each side of the center line, excepting at the station, where the railroad company's property extends in width 100 ft. on the east side from the center line of the track, and in length from the north boundary of the map to the highway. On the west it extends in width 200 ft. from the center line of the track and in length from the north boundary of the map to the Benton road. At a point 390 feet from Sta. 43 + 72.5 of the main track, as measured on the west right of way boundary, is the end of the boundary line between lands of James Henderson and John Andrews, the bearing of which is S 57° 45′ E. This boundary extends to the west boundary of the map. At a point in the center of Hall road, 10 feet west of intersection *G*, is a corner at the schoolhouse lot which fronts 100 feet on Hall road, and 220 feet in depth, as measured from the center line of the road, the sides being at right angles to the center line of the road. *All property lines bounding on or intersecting highways follow or extend to the center line of the highway.* Immediately adjoining the schoolhouse lot on the west is the lot of John Stark, with front of 200 ft. and depth of 220 ft. A point 300 ft. east of intersection *G*, as measured on the center line of Hall road, is a corner of lot of F. Swartz. This

boundary is at right angles to the center line of Hall road and extends to the center of Prospect road. The other boundaries of the lot are marked by the center lines of the roads upon which the lot fronts. At a point 300 ft. south of intersection *H*, as measured on the center line of the old turnpike, is a corner of lot belonging to John Edwards. The sides of the lot are at right angles to the center line of the turnpike and the ends parallel. The lot fronts 300 ft. on the turnpike and has a depth of 425 ft. The south boundary of this lot forms a part of the north boundary of a lot belonging to Jane Gregory. A line joining the southwest corner of John Edwards's lot with the northeast corner of Henry Watson's lot completes the north boundary of the Gregory lot. The bearing of this line is N 87° 10′ E. The west boundary has a bearing of N 4° 45′ E, and extends to the center line of Waverly road, with which it forms an angle of 90°. The south and east boundaries of the lot are formed by the center line of the Waverly road and the old turnpike, the courses of which are already given. The point of intersection of the center line of the Waverly road with the old turnpike is a corner of lot belonging to A. Atherton. The north boundary extends along the center line of Waverly road 425 feet; thence, at right angles to that road, S 4° 45′ W 420 ft.; thence, on a line parallel to the Waverly road, to the center of the old turnpike. The west boundary is formed by the center line of the turnpike.

The west boundary of lot belonging to Jane Gregory forms the east boundary of lot belonging to Henry Watson, which has a frontage of 150 feet and a depth of 220 feet. The west boundary of Henry Watson's lot forms the east boundary of lot belonging to James Lenox, and extends N 4° 45′ E 220 from the center of the Waverly road. Thence, N 85° 15′ W to the center of the Scranton turnpike. The remaining boundaries of the Lenox lot are formed by the center lines of the adjoining highways. By prolonging the boundary between Henry Watson and James Lenox northward 275 feet, we form the east boundary of John Andrews's lot. The same line prolonged to the center

of Hall road forms the east boundary of Clayton Andrews's lot. The boundary between lots of John and Clayton Andrews is formed by the center line of the lane, and that center line produced to the east boundary of the lots. The remaining boundaries of these lots are formed by the center lines of the adjacent highways. At 210 feet from intersection *C*, as measured on the center line of the Waverly road and Lenox lane, is the northwest corner of a lot belonging to the Lenox estate. This lot has a front of 60 feet and a depth of 180 feet, the sides being at right angles to the center line of Lenox lane.

All buildings the student will locate by eye, giving to them the same shape and proportions as shown in the plate. Shade trees are spaced 50 feet, their rows being placed 10 feet inside the road boundaries. Fruit trees are spaced 40 and 30 feet. The usual conventional signs are employed to represent the topography. As grass and cereals are much alike in appearance, the conventional sign for grass may be varied so as to represent them all and so give variety to the drawing. A part of the lot belonging to James Henderson is occupied by a vineyard, which is represented by rectangles enclosed in wavy outlines. These signs might also be used to represent small fruits growing on trellises. All other conventional signs employed have been previously described, with appropriate illustrations.

1386. Colored Topography.—All conventional signs so far described are made with a pen. Often, where surveys cover extensive areas, the labor and time for pen work can not be spared, and colors applied with a brush are used instead. With a skilful hand, work of this character may be rapid and very effective. But three colors besides India ink are required; gamboge (yellow), indigo (blue), and lake (scarlet). The colors used in the drafting room are of two kinds, viz., *dry* and *moist*. Dry colors are sold in the form of rectangular cakes, wrapped in tin foil. Moist colors are packed in small dishes of porcelain. These dishes are rectangular in form, open at top. The surface of the paint

is covered with wax and the entire dish wrapped in tinfoil. In using, rub the cake of color with a moistened brush which will take up sufficient color. Dilute the color in water to the proper tint, which should always be light and delicate. To cover a surface with a uniform tint, use a camel's hair or sable brush. Use a separate brush for each tint and provide plenty of dishes for the various colors. Confusion in the use of brushes is sure to spoil a tint. For large masses of the same tint, a large brush should be used, but for vegetation or small details, small brushes are indispensable. Avoid heavy strokes. Light and rapid strokes produce smooth and pleasing effects. The map should be pinned to a light drawing board, so that it may readily be inclined at an angle. Keep the brush well filled with color and begin at the top of the surface, inclining the board towards you. If the outline is very irregular, moisten the edge with water. Apply the tint the full length of the surface and continue it down the surface, *never allowing the edge to dry*, which is the secret of a smooth tint.

Woods are commonly colored yellow; grass land, green, made of gamboge and indigo; cultivated land, brown, made of lake, gamboge, and India ink; brushwood, marbled green and yellow; vineyards, purple, made of lake and indigo; lakes and rivers, of light blue, with a darker tint at the shore line; seas, dark blue, with a little yellow added; marshes, the water blue, with patches of green applied horizontally, and roads, dark brown. Woods may be made very effective by drawing the trees, coloring the angle towards the light (the upper left hand) with a touch of yellow, and indigo on the opposite, or lower, right-hand side.

Skill and judgment in mixing and applying colors can be acquired only by practice. When a combination tint, such as brown, is required, the draftsman must estimate how much coloring is required and provide accordingly. He is liable to use too much color producing a heavy tint, which is almost certain to become streaked when applied. A separate brush should be used to take up each color, the

brush being moistened and rubbed on the cake. A tinting dish of either glass or porcelain contains the water. The brushes carrying the colors are dipped into the water, each giving off its proportion of color. The water is then stirred until every particle of color is dissolved. If the tint is too light, add more color; if too heavy—a common fault—add more water until the proper shade is obtained. Any tint is deepened by repeating the application of it. When a tint is to be shaded from light to dark, give the entire surface one coat, which will give the lightest shade. Decide how many coats are to be applied to produce the deepest tint and divide the length of the surface into the same number of equal spaces. Beginning at the top of the surface to be shaded, apply a second coat, stopping one space from the bottom. Then take a clean brush and dip it into clear water and wash the edge of the second coat at its finishing line, brushing downwards, taking up in the brush all excess of coloring matter. Another coat is then applied, commencing again at the top and stopping two spaces from the bottom, washing down the edge with clear water. The paper must not be allowed to dry between the successive applications of the tint. If from any cause it should become dry, the entire surface must be moistened with clear water before another application of the tint. Careful practice will enable the student to produce a smooth tint. When a marbled effect is desired, first cover the entire surface with one tint and then apply the other in shorter or longer strokes of the brush, according to the effect which it is desired to produce.

In tinting shore lines, first trace the outline of the shore with a brush moistened with clear water, extending the wash as far as the tint is to be used. Prepare a color dark blue in shade. Next dip a fine brush in the color and trace the outline of the shore. The adjoining paper being moist will cause the color to run. Then moisten a brush in clear water and wash the shore line, the strokes of the brush being drawn from the shore. The effect will be a dark blue shore line shaded to light blue. The dark brown color for roads is

produced by adding India ink to the brown representing grass land.

1387. Scales. — The scale of a topographical map should depend upon the character of the work involved, but should always be large enough to clearly admit all necessary details without making the map unwieldy. The work should be so well done that dimensions may be accurately scaled from the map without any calculation. For small plats, such as public squares and small parks, 50 feet to the inch would be a suitable scale, admitting the smallest detail. For larger areas, such as town sites, extensive parks, suburban resorts, etc., a scale of 200 feet to the inch is commonly used. The scale must be reduced in proportion as the area is increased. Published topographical maps are usually made to a scale of one inch to the mile, admitting of the representation of all towns, villages, farms, woods, isolated buildings, and every stream of 600 feet in length, and every hill of 100 feet in height and 500 or 600 feet in horizontal extent.

On a scale of two inches to the mile, the various features of the ground can be clearly and accurately represented. All streams of 300 feet in length, every pond not less than 50 feet broad, and all towns, villages, roads, foot-paths, farms, and isolated buildings.

A scale of six inches to the mile is best for military purposes, admitting of a complete delineation of a country. In all cases the character of the surface and the purpose of the map should determine the scale.

1388. Size of Maps.—Maps for use in the field may vary in size from 18 by 24 inches to 24 by 30 inches. Both sizes are suitable for railroad work. The lines should be so arranged on the different sheets that they may be fitted together, making a continuous map of the line of survey. The sheets should be numbered in regular rotation, and when pinned together they will appear as shown in Fig. 354.

Where possible, arrange the sheets so that each curve

with its center and limiting radii may come on the same sheet. Sometimes this can not be done. The points where the different sheets join on to each other should be fixed by a line drawn at right angles to the center line or radial line

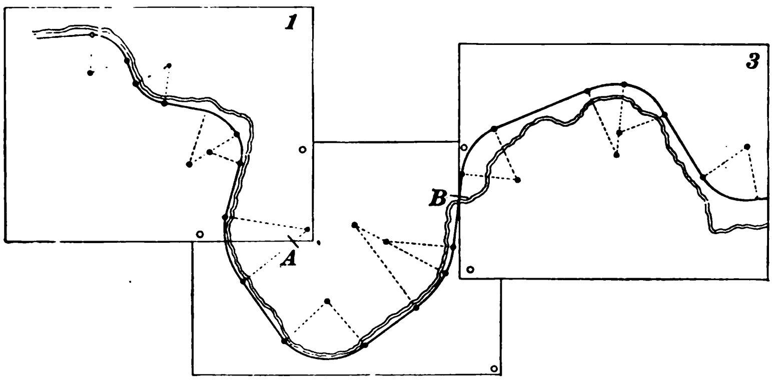


FIG. 354.

at the point of junction, as at *A* or *B*. This simplifies the work of fitting the sheets and greatly promotes accuracy.

1389. Lettering.—Legibility and uniformity are the requisites for good lettering. Ornamental letters, excepting for titles, are entirely out of place, and they are only admissible for titles of very elaborate maps. All lettering in the body of the map or details should be in italics. Small letters should be two-thirds the height of capitals, ordinary capitals $\frac{1}{8}$ of an inch in height, and small letters $\frac{2}{3}$ of $\frac{1}{8}$ or $\frac{1}{12}$ inch in height. Uniformity in spacing letters is as important as uniformity in size. There is no work where practice is more essential, if skill is to be acquired, and nothing adds more to the finish of a drawing than good lettering, while poor and slovenly lettering will rob of all merit an otherwise perfect drawing.

1390. General Instructions.—If the entire map is to be contained on a single sheet, judgment is required in fixing the direction of the first course so as to attain that result. The points of the compass must also be in their

natural order, viz., *North* at the top of the map and *South* at the bottom.

The outline of the map will determine the position of the title. Very *fine* lines are a blemish rather than a merit, and heavy lines are likewise to be avoided except when used for shading or boundaries. Boundaries of private property are represented by bold, full lines, and those of state, county, or municipality by heavy broken and dotted lines. All dimensions should be expressed in figures, and all important lines and objects briefly but accurately described.

RAILROAD LOCATION.

1391. Need of a Railroad.—This subject presupposes that there is, beyond a doubt, *need*, both *present* and *prospective*, for the railroad whose location is to be decided upon.

1392. Available Capital.—The first duty of the Chief Engineer is to *know how much money* those having the direction of the enterprise, commonly known as *the company*, have or can command, as all subsequent operations will be governed by that fact alone. Having obtained that information, he collects all available maps of the country to be operated in, and from them derives a general knowledge of the mountain ranges, valleys, rivers, together with their tributaries, and the location of all towns and villages lying within that territory, their relative size and importance.

1393. Terminals.—The **terminals** or extremities of the proposed railroad are known, and the first problem before the engineer is to determine the general route which the line connecting them should take. A careful study of the maps in hand will indicate to him the different possible routes whose comparative merits he can know only by careful investigation. The number of these possible routes will probably be further reduced by the location of certain towns which must be reached for traffic considerations. These towns will divide up the line into two or more sections, each offering considerable range in choice of location, which indicate to the engineer the scope of the country to be covered by the *reconnaissance*.

1394. Important Considerations.—The engineer should preserve an optimistic habit of mind, believing nothing to be too difficult to be overcome, and fully expecting

to find a line in every way superior to that which had been regarded as possible. It is of the highest importance that he should regard the proposed line from a business point of view, and be able to distinguish between what is *commercially important* and *physically important.* He should keep constantly in mind this vital fact, viz., that a line of railroad is built for the purpose of *making money for its projectors;* that any expenditure which will add proportionately to the earning power of the road is *wise*, and that any which will not is *criminal waste.*

1395. Relative Economy.—The engineer must, however, be able to distinguish between wise and unwise economy. Because a line is brought to sub-grade *cheaply*, it is not necessarily *economical grading.* It requires an average continuous cut and fill of 7 feet, with the usual proportion of masonry, to equal the cost of the superstructure, i. e., ties, rails, fastenings, and ballast, while the cost of rolling stock, machinery, buildings, etc., of an active road, cost nearly as much as roadbed and track complete.

1396. Towns and Terminals.—Towns, which are always the main sources of traffic, and terminals, which, besides being sources of traffic, are the main points of traffic exchange, are considerations of vital importance to the road. No expense within the possible reach of the company should be spared in reaching the heart of towns and in providing the best traffic facilities. A small saving in time and a small increase in comfort will, other things being equal, secure the traffic. Where the new line comes into competition with old and favored lines, no pains which tact or ingenuity can devise should be spared to induce favor and patronage. It is at such a juncture that tact and enterprise count. No source of business, however insignificant, should be overlooked, and every point gained should be held at any reasonable cost. *Provide ample terminal grounds at any possible cost;* with them a new road will have a hard fight, while the lack of them places the road at a great disadvantage from the first, and may cause its ruin.

1397. Comparative Cost of Different Lines.—In order that the engineer may correctly estimate the comparative cost of different lines, he must know the actual cost of work of various kinds, and be able, from his examinations of the country, to properly classify it. Experience in the location and construction of other lines will alone enable him to decide between the comparative merits of the different routes.

The almost universal fault of engineers is to *underestimate* cost, a fault common to all persons who are about to undertake construction of any kind. Experienced engineers make it a rule to add 10 per cent. to the estimate which is intended to cover all possible cost.

1398. Considerations Which Determine the Route.—Traffic and engineering considerations will usually reduce the possible routes to *two* if not to *one*, thus narrowing the field of operations. The work of reducing the traffic and engineering possibilities of a section of country to their *lowest terms* is emphatically the work of the chief engineer, and is embraced in that most important, though much misunderstood, term, viz., the *reconnaissance.* Let the young engineer keep prominently before his mind that the largest half of a railroad survey is the reconnaissance. Let him ponder well the varied interests and problems which confront him, and let him know his country before he drives a stake. This knowledge can be had only by hard work and a good deal of it.

RECONNAISSANCE.

1399. General Directions.—Having provided himself with the best available map of the section immediately in hand, an aneroid barometer, and a guide who is famlliar with the section, the engineer is ready for a start. He should avoid highways if he is to acquire the knowledge he is seeking, as they give the traveler an erroneous impression of the character of the surrounding country. He unconsciously believes because the "walking is good" that the

surrounding country is smooth and tractable, and obstacles to railroad building few and insignificant. On the other hand, by taking a *cross-country* route, he will be likely to exaggerate those obstacles, simply because they have impeded his travel. All experience goes to prove that in America, at least, the railways avoid the highways; not through the intent of the engineer, but, as it were, in silent condemnation of the incapacity of those who directed their building. The engineer should keep constantly in mind that his examinations are not to be confined to the strip of country within his immediate vision, but are to cover a range of several miles on either side of his line of march. Much information he can obtain from his guide; more he must find out for himself—taking nothing for granted where a doubt is raised. Very often an apparent obstruction which, did it really exist, would effectually bar the way, will disappear upon a careful inspection of the country, or at the worst prove an insignificant obstacle compared to those already passed. Obstacles to travel are not necessarily obstacles to railway building. Narrow defiles, obstructed by boulders, underbrush, and timber will, when cleared, appear comparatively smooth.

1400. Use of the Hand Level.—The hand-level is of the greatest value, and should be in constant use. The unaided eye is of little use in estimating comparative elevations. The hand level determines relative heights, constantly affording needed information and saving much time, which, without it, would be spent in useless tramping.

1401. Keeping Notes.—A careful record should be kept of all streams encountered; their direction, and of what larger streams they are tributaries.

The sizes of different streams in the same section, to a certain degree, determines their relative elevations. The larger the stream the lower its elevation. The velocity of its current, in a measure, indicates the grade of a stream, though a fall which would make a torrent of a river would give but a feeble current to a shallow stream. The recon-

naissance should cover a complete section of the proposed line before the work of actual survey is commenced, though it is not to be considered as complete until the final location is fixed.

1402. Deceptive Appearances of Country.—The natural eyesight is easily deceived, and rarely gives to objects their true relative proportions. Two reasons for this deception are the following:

First, the eye foreshortens the distance in an air line, and exaggerates a lateral offset. This fact is illustrated by Fig. 355, in which let the points *A* and *B*, which are 10,000

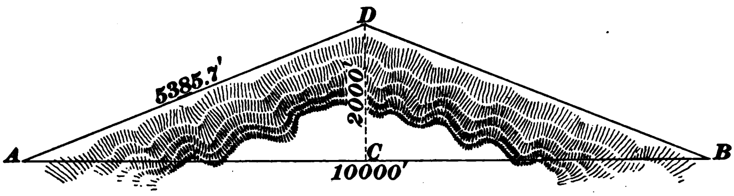


FIG. 355.

ft. apart, be in an air line between two towns, and suppose this line to cross a ridge, the highest point of which is at *C*, and that the ridge flattens out at *D*, 2,000 feet from *C*, the middle point of *A B*. To the inexperienced, the offset *C D*, as seen on the ground, will be greatly exaggerated, appearing to be fully one-half the straight line *A B*, and the conviction will follow that in passing from *A* to *B* by way of *C*, not only will a great deal of curvature be introduced, but the length of the line will be so greatly increased over that of *A B* as to make a careful consideration of the route out of the question; even though the line *A B* should require steep grades and a heavy cut at *C*. This exaggeration is apparent when we find by calculation that the distance from *A* to *B* by way of *D* is only 770.33 ft. greater than the direct line between *A* and *B*. This illusion of the eye explains the aversion to *swinging the line*, too common among engineers, and the undue importance attached to *good alinement*. The chances are *four* to *one* that the line *A D B* is immensely superior to the line *A B*, both in cost

and grades, while the increase in distance of the line *A D B* over the line *A B* is less than 8 per cent.

Frequently a deflection, which will not, in reality, add more than 15 per cent. to the length of a line, will appear to double it, and the deplorable mistake is often made of adopting the air line, even though it cost 25 per cent. in excess of what the deflected line would cost.

Second, the eye exaggerates the sharpness of projecting points and spurs and the degree of curvature necessary to pass around them. All slopes when looked at from in front, are exaggerated by the eye. Few mountains have slopes exceeding $1\frac{1}{2}$ to 1 or $33\frac{1}{3}°$, yet the eye will estimate such a slope at from 45° to 50°.

In running the line *A B C D*, Fig. 356, the engineer, if he were to accept his natural estimate of the angles at *B* and *C*,

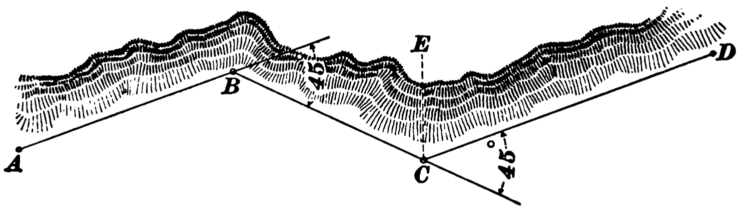


FIG. 356.

would make the angle at *C* about twice as large as the angle at *B*, even though he had walked over the line. The reason for this is that while standing at any point on the line *B C*, his view of the line *C D* is cut off by the profile *E C* of the hill in front, and, in spite of himself, the unseen will be distorted and invariably *magnified.*

Nowhere is the proverb, "appearances are deceiving," so true as in an apparently smooth or gently rolling country. The undulations are so gradual that their aggregate is rarely suspected. Abundant experience goes to prove that an air line in such a country is only possible at the cost of heavy grades and long and heavy cuts and fills. To avoid them, frequent deflections must be made, introducing curvature in proportion, though the increase in length of line is in no

degree proportional to the saving in cost of construction and operation.

1403. Discredit All Unfavorable Reports.—An unfavorable report of a locality, more than any other, should challenge a careful examination. The inexperienced are easily daunted by obstacles which are really insignificant. A section heavily timbered and covered with boulders, and appearing to them as forbidding in the extreme, would likely show an alinement and grades incomparably better than the line of their choice. In reconnaissance it is the unexpected which happens, and the line which appears least promising will often prove, by far, the best.

1404. Choice of Lines.—Never believe that only one line is possible. There are always two, and generally sev-

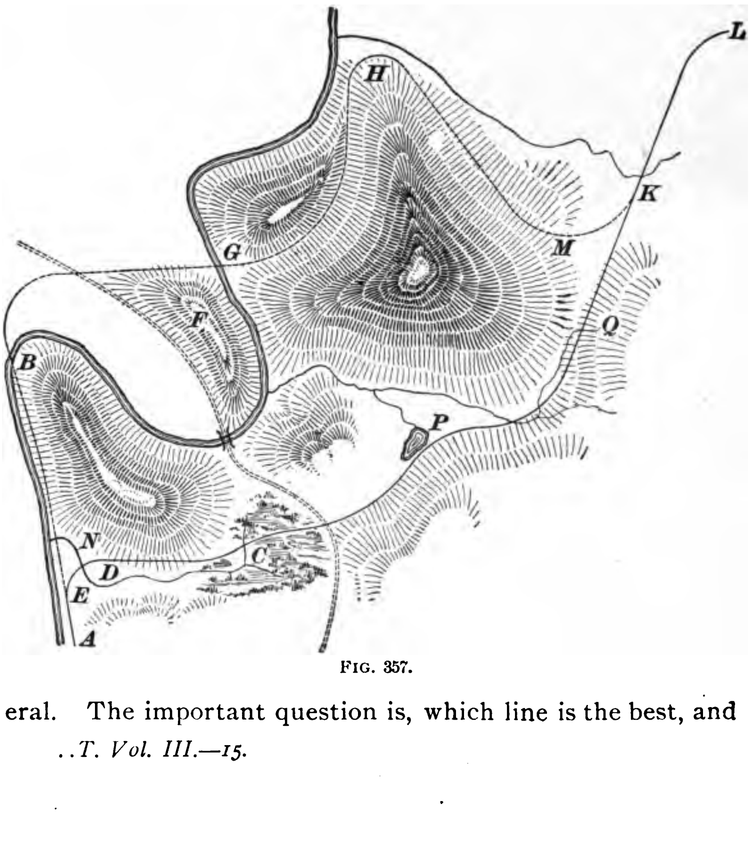


FIG. 357.

eral. The important question is, which line is the best, and

that is the one to settle upon. The following instance well illustrates this point. The facts in the case are shown in Fig. 357. The line had followed the river *A B* for several miles, keeping a uniform grade of about 30 feet per mile. It became necessary to leave the river valley and climb a ridge in order to reach a town lying in another valley. The entire country was thickly covered with timber and undergrowth, and consisted of abrupt, irregular hills, called hog-backs. The brook *C* was known to the engineer, who endeavored to trace it to its junction with the river, but the brook lost itself in a cedar swamp at *D*, and it was impossible to find the outlet. After repeated effort to find the outlet and encountering each time the ridge *E* which lay between the river and the valley *D C*, he continued the line up the river, crossing it at *B*, where a precipitous ledge prevented further progress along the river, and crossing the neck of land *F*, and the river at *G*, commenced to climb the ridge doubling about the sharp headland at *H*, and then swinging backwards, making the line *K L* with a heavy fill at *M*. This seemed the only possible line, but it was so rough and crooked that the engineer determined to make another trial. He spent two days in hard tramping during a continual downpour of rain, discovering the narrow opening at *N* through which the brook found its way. He also found the brooks *P* and *Q*, and blazed a line through from *E* to *K*. A line was then run, following this course with the most satisfactory results, saving two river bridges and three miles in distance, though getting through the ridge at *E* entailed a heavy cut. The railroad company was opposed to any further investigation after the completion of the first line, as a month of hard work had been expended upon it. Yet the saving in first cost accomplished by the adoption of the second line over the first would have paid the engineering expenses of the entire line of 100 miles. In general, a better line than the one already in hand can be found by looking for it.

1405. Advantages of Valley Lines.—Wherever possible, stick to the valleys. Bottom lands, though low-

lying, are generally above flood line, or, if below it, are only covered by back-water, else they would have been long since washed away. Though a crooked channel may necessitate frequent and sharp curves, yet they are more than compensated for by the low grades fixed by that channel. As frequently happens, the bends in the channel are caused by projecting heads of hills. These sharp and often rocky points usually require but short cuts, and furnish the best of material for the adjacent embankments.

Notes should be kept of all important information gained. Points where two promising lines diverge should be so marked as to be readily recognized.

The reconnaissance being completed and all economical and topographical questions settled, the next duty of the engineer is the preliminary survey. The party should be organized and all ready for service the moment the reconnaissance and general route is decided upon.

1406. Organization of Party.—The size of the party will depend upon the character of the country in which the work is to be done. If thickly settled, smaller; if thinly settled, larger.

A well-equipped party in ordinary country should number sixteen men, as follows: The transit party, comprising chief of party, transitman, two chainmen, three axmen, one stakeman, and one back flagman; the level party, comprising the leveler, rodman, and one axman, and the topographical party, comprising the topographer and two assistants. The last to be named, though not the last in point of importance, is the teamster, who should be provided with a strong, active team, and spring wagon that will not break down. It is a most wasteful economy to require a party to walk from two to five miles before commencing work, and then to quit work in time to make another long tramp before reaching shelter. A chief of party who does not know the necessity for a team and insist upon having it, is not fit for the work in hand. No company will refuse to provide it, if the matter be properly presented, yet many parties are

deprived of this important part of the outfit. If the party are living in camp, a team is an absolute necessity for moving the camp, which will be done at least once a week, and usually once in three or four days.

1407. Camp Outfit.—For camp work the following outfit will be necessary:

Two wall tents with flies, or extra roofs, for the accommodation of the men, and, if the work is to be carried on during the winter season, a tent must be provided for the team; a sheet-iron stove and provision chest for the commissary; a cook who can prepare wholesome food and plenty of it, and keep himself and belongings clean and orderly; a drafting table, which is nothing more than a large drawing board, a straight-edge and triangles, an ordinary pocket case of drafting instruments, together with a beam compass, will answer for all preliminary drafting. Drawing and profile paper, note books, etc., are carried in a camp chest. Each man provides his own bedding, which consists of blankets alone.

The field instruments will comprise the following, viz.: A surveyor's compass, plain transit, and transit poles, **Y** level and Philadelphia leveling rod, aneroid barometer, clinometer, slope rod, chain, axes, marking crayons, tacks, and stake straps about the width and length of ordinary trunk straps. A supply of stakes should be kept constantly on hand. If possible, have these of light, well-seasoned wood (pine is best) and of the following dimensions: Length 2 ft. 6 in., width 2 in., thickness ½ in., and planed on one side so as to admit of easy and plain numbering. Special conditions may require additional equipment, but the above outfit will meet all ordinary requirements.

1408. The Compass for Preliminary Work.—If the section be comparatively free from iron deposits, the preliminary line should be run with the compass, for in spite of small inaccuracies in alinement due to errors in reading the needle, the average accuracy of a number of readings will closely approximate to those read with the transit

vernier. The comparative advantages of compass and transit for *preliminary* railroad surveys was discussed in Art. **1217.** Suffice to say, that where the conditions warrant it, the compass is always the more economical and expeditious instrument. If, however, iron exists in quantities sufficient to hinder the perfect freedom of the magnetic needle, the compass must be discarded for the transit, with the injunction to never record an angle without first checking it; and after recording, read the angle a second time. The assurance of accuracy is worth many times the labor and care of checking work.

FIELD WORK.

1409. The Starting Point.—In general, the starting point of the survey will be at an extremity of one of the sections into which the proposed line is divided. If it is to connect with some already existing line, a point on that line is taken; if not, a street line or some other fixed boundary is chosen and the line *tied into it*. The chief of party accompanied by a flagman, goes ahead and fixes the points where the angles are to be taken. The flagman carries, besides the transit pole, an ax for making plugs, one of which he drives flush with the ground at every transit point. A galvanized tack, or, better still, a small galvanized nail, is driven in the center of the plug and the transit pole (flag) held on the point while the transitman reads the angle. A point having been fixed, and the flag set up, the transitman measures the angle between the boundary at Station 0 and the first course. The angle and bearing of the line being recorded, the transitman walks *rapidly* to the point where the flag is standing and sets up the instrument at that point. The head flagman should carry about a dozen pieces of red flannel to be used as targets. As soon as a transit point is set and the transitman has signaled that the angle is read, the flagman should tie a piece of target flannel to a light stake of about the same length as the transit pole, and plant the pole firmly in line directly behind the

plug or transit point. This affords the chainman a good target for *lining in*, and allows the flagman to join the chief of party who has gone ahead to select another transit point. The transit being set up, a backsight is taken to a flag held at the starting point (Station 0). The bearing is then checked and the angle turned to the next point ahead. The chainmen having come up with the transit, they report the number of the station of the transit point to the transitman, who records it in the transit book. He then directs the chainman on the next course, reads the forward angle and records it together with the bearing of that course, and then *moves up* to the next transit point.

1410. The Level Party.—The level party follows the transit party as closely as possible. The levels of the proposed line and the line with which it is to connect should be referred to the same datum plane, so as to secure a continuous profile; especially if the levels of the established line are referred to the *sea level.* If such a base is not practicable, an elevation for the starting point must be assumed, but of such a height as will bring all elevations of the proposed line above the assumed datum plane.

In case the country is wooded, with the added hindrance of thick underbrush, the transit party will of necessity move slowly, and the level party will consequently have much spare time on their hands. They should provide themselves with profile paper and keep the profile platted as the work progresses.

1411. Bench Marks.—Bench marks are established at intervals of from 1,000 to 1,500 feet, according as the line is rough or smooth. At every stream which the line crosses the elevation of the surface of the water and of the bed of the stream should be taken. If there are any marks indicating the elevation of high water, a rod reading should be taken at such point and a record made of it.

1412. The Topographical Party.—The topographical party follows the level party, though their rate of progress will be more uncertain than either of the parties preceding

them. Where the slopes are uniform, they need not be taken oftener than every third or fourth station. If, however, the country is broken and rough, it may be necessary to take them at each hundred feet, and with great minuteness.

1413. Office Work.—At the conclusion of each day's work, the field notes, both transit and level, are carefully checked, and a plat of the line is made, either by tangents or by latitudes and departures, carefully marking the crossings of streams and highways, and noting any important point which would enable the chief engineer to readily locate any particular section of the line. Where the country is smooth the line may be platted to a scale of 400 feet to the inch. Rough parts of the line may not exceed a scale of 200 feet to the inch, and where difficult country is encountered, involving detailed topographical maps, a scale of 100 feet to the inch is advisable. Plat the line on sheets 24″ × 30″ in size, numbering them in regular order, each sheet containing a part of the line on the immediately preceding sheet, so that by matching and pinning them together, there may be had a continuous map of the line. So arrange the line on the different sheets that when the paper location is made they shall contain as many curve centers as possible.

The topographer will do his proportional share of the work, which will consist mainly in a detailed explanation of the notes of the day's work to the draftsman, whose principal work is the contour maps. The leveler will plat the day's levels on the continuous profile kept in the office, the rodman reading the notes. This profile will contain as full information as possible, especially relating to highways and watercourses.

Some engineers prefer to wait for a rainy day in which to do the office work, but more make it an invariable rule to plat each night the work of the day. This practice enables the chief of party to have a complete record of his work always ready for the inspection of the chief engineer, who

is liable to appear at any time. If he is his own *chief*, personal interest in the work would warrant him in making such a rule. Notes which are platted when *fresh* are always of more value than when *stale*, and the daily office work unites the different parties which are separated during the day, sustaining a common interest in the work. If the contour maps are to keep pace with the survey, the draftsman must be an expert. Each day he plats the work of the preceding day, and under the direction of the topographer, every point is covered.

1414. Spur Lines.—At certain points of the main line, two and sometimes three different routes will present

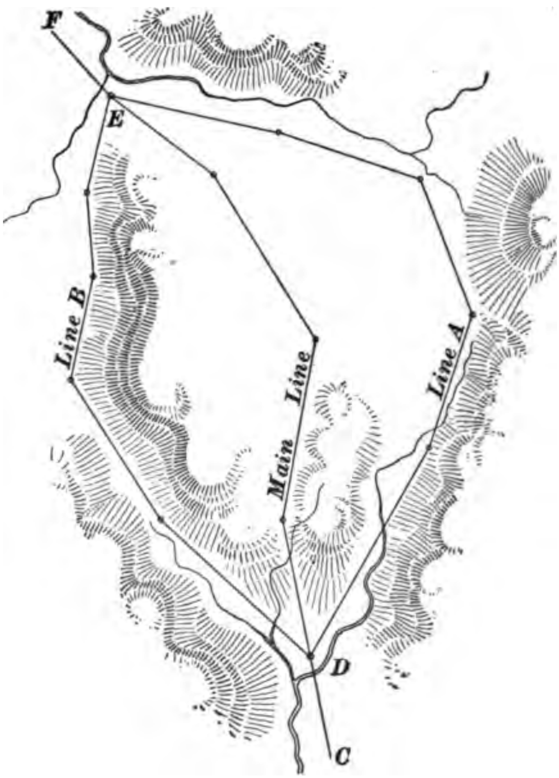


FIG. 358.

themselves for reaching another point of that line, and require the running of *spur lines* to determine the most advantageous route. The main line being run, the spur lines are *tied into* it, designating them by different letters, as line A, line B, etc. The comparative advantage of the different alinements will show themselves in the *plat*. Their comparative profiles are commonly shown by platting them in different colors. A case requiring spur lines is shown in Fig. 358. Here the general direction of the main line is $C\ D\ E\ F$, D being the point where the spur lines A and B diverge from the main line, and E where they again unite. It will be evident from an inspection of the map that the main line is superior to both the spur lines in point of alinement. Their comparative lengths are already known. With the comparative profiles before the engineer, he, knowing the nature of the ground on the different lines, will have no difficulty in making a judicious choice of lines. Sometimes where the merits of the different lines are nicely balanced, it becomes necessary to locate on two lines and base a decision upon actual estimate of cost of construction.

1415. Gradients.—The preliminary survey having been completed, a careful study of the profiles will enable the chief engineer to establish a gradient whose *maximum* will *limit* the *train loads* passing over it.

The character of the expected traffic will greatly modify this maximum. If the road is to do a passenger business principally, the gradient may be raised, but if the bulk of the business is to be freight, the gradient must be placed at the lowest possible limit which the finances of the company and the nature of the country will permit.

Should all the heavy grades occur on a short section of the line, it may be policy to mass them within the smallest possible limits and proportionately reduce the gradient of the remainder of the line. In such an arrangement of grades, an assistant engine would be used on the summit section, and so cover the entire line without any change of train loads.

1416. Curvature.—There is no absolute rule for limiting curvature. The approximate limit will depend upon the topography of the country and upon the character of the expected traffic, a freight traffic admitting a higher and a passenger traffic requiring a lower degree of curvature. For all ordinary traffic conditions, i. e., where freight and passenger traffic will be about equal, the invariable rule is *use such curves as will best conform to the existing topographical conditions.*

Any curve up to 10 degrees will be no obstacle to a speed of 30 miles per hour, the average speed of passenger trains. This affords a range in curvature which will meet the requirements of most localities.

Curvature is no blemish to a line, if it secures the great advantages of low gradients and moderate cost. At points

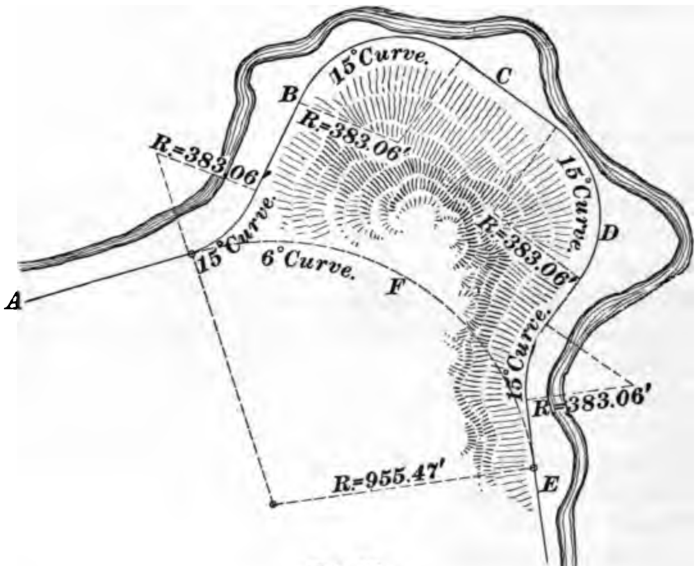


FIG. 359.

where moderate curves are possible only at great cost, it is often a wise policy to build a temporary line, using sharp curves, and put off the expensive work until the financial strength of the company warrants its undertaking.

An instance where a temporary line is expedient is shown in Fig. 359. Here the track follows the windings of a stream in a narrow valley, whose sides are steep and rough. Unless the company is financially strong, it will be much better policy to build the line *A B C D E*, using curves as high as 15°, and reducing cost to a minimum, than to build the line *A F E*, giving a single curve of 6°, but requiring a heavy rock cut at *F*, or perhaps a tunnel at that point. The line *A F E* is always possible, and when the road has built up a paying traffic and finances are easy, the cut or tunnel at *F* can be made without interfering in any way with traffic, and, in all probability, at much better prices than when the temporary line was built.

The question of gradients being decided, a preliminary profile is made, which will serve as a basis for a paper location.

1417. A Paper Location.—The paper location is substantially the one which takes permanent form in the final or located line. It is laid down on the contour maps, which contain all the information accumulated by the preceding surveys. The grade for each station is taken from the preliminary profile and marked on the contour maps opposite the corresponding station. This is readily done, as the contours are but five feet apart, and intermediate elevations can easily be estimated. These grade points are commonly marked by small red dots enclosed in small circles of the same color, and show where the plane of the grade would cut the surface of the ground. A piece of fine thread is then stretched, covering as many of these points as possible, and a pencil line drawn in place of the thread. This pencil line will locate a tangent on the map. In the same way any number of tangents may be located.

A set of office curves will be of great assistance in fitting curves to the tangents, the curves like the tangents following the grade line as nearly as possible. Having determined the degrees of curve uniting the tangents, the intersection angles are calculated by tangents and the

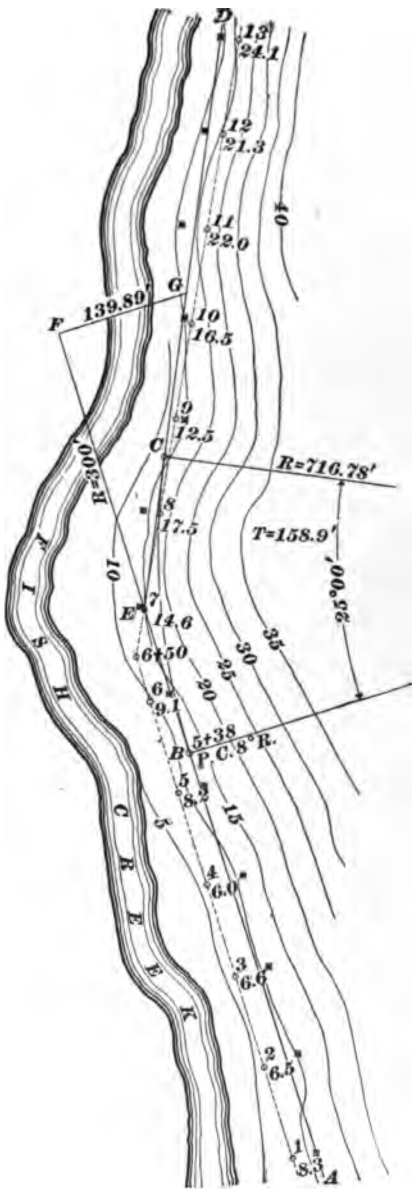


FIG. 360.

tangent distances accurately scaled from the intersection points.

1418. Field Notes from the Paper Location.—In taking notes from the paper location for actual field work, the points of curve and points of tangent should be carefully referred to fixed points in the preliminary line (either stakes or plugs, the latter are preferable) so that if, upon the completion of any curve, the following tangent does not take the position prescribed for it in the notes, it may be *swung* into that position. It is impossible, especially in a rough country, to make the actual measurements agree with the calculated measurements, hence small inaccuracies need cause no concern.

The platting of a paper location is illustrated in Fig. 360. Here the grade of the line is determined by the grade of the stream, which it closely follows. The grade averages .5 per cent. The preliminary line is shown dotted, and

the located line is drawn full. Let the grade for Sta. 1 be 11.0 feet. The grade for Sta. 2 will, therefore, be 11.0 feet plus .5 foot, or 11.5 feet. The grade for Sta. 3 will be 11.5 + .5, or 12 feet. By the same process we find the grade for each of the stations given in the plat. The grade for each station is then marked on the contour map opposite the corresponding station of the preliminary line by a small dot enclosed in a circle. Straight lines $A\ B$ and $C\ D$, which are to form tangents in the paper location, are then drawn, covering as many of these small circles as may be, and produce, until they intersect at E. The line $A\ E$ is then produced to F, making $E\ F = 300$ feet or any other convenient length of radius suitable for measuring the intersection angle by its tangent. At F erect the perpendicular $F\ G$, which will be the tangent of the intersection angle $F\ E\ G$. Measuring $F\ G$ by scale $F\ G = 140$ feet, though by calculation 139.89 feet. Dividing 140 by 300 we have a quotient of $.4667 = \tan 25°$. We find by trying different curves that an 8° curve will most nearly cover the grade points between the tangents $A\ B$ and $C\ D$. From formula **91**, $T = R \tan \frac{1}{2} I$ (Art. **1251**), we find the tangent distance = 158.9 feet. Scaling from the intersection point E on both tangents this distance we locate the P. C. and P. T. The station of the P. C. we determine by scaling from the P. T. of the last curve. The station of the P. T. is, of course, found by calculation.

1419. Paper Location Profile.—A profile, called a **paper location profile,** is made from elevations taken from the contour map at each station of the paper location, and a grade line drawn on it which should be substantially that of the final location, and if the preliminary work has been thoroughly done, the discrepancy will be but slight.

1420. Actual Location.—The location party has the same organization as the preliminary party, excepting the topographer and his assistants. Their work is supposed to be completed. The chief of party carries, besides the notes of the location, which is to be *run in on the ground*, the map

covering the section immediately in hand, as not infrequently it is necessary to slightly modify the paper location. He will need in addition a short scale and compass carrying a pencil point.

Where the country is open, it is good practice to locate the tangents by offsets from the preliminary line and make the intersections on the ground; but if the ground is covered with brush or timber, the paper location must be strictly followed, and the results will generally fulfil all reasonable expectations.

PROBLEMS IN LOCATION.

1421. Problems in Location.—The tangents being fixed in the paper location, the purpose is to so fix the point of curve, the P. C., that, the curve being run, its tangent shall coincide with the following tangent as laid down in the paper location. Frequently, the actual tangent fails to coincide with the theoretical tangent, in which case it must be *swung into place*. Sometimes the tangents not only fail to coincide, but form an angle with each other, in which case the central angle of the curve must be either increased or diminished, as the case demands. These modifications of the paper location give rise to the following problems, which will cover all ordinary cases:

1422. Problem I.—To change the P. C. of a curve so that the curve shall terminate in a tangent parallel to a given tangent and at a given distance from it:

Let $A\ B$, Fig. 361, be a curve terminating in the tangent $B\ C$, and it is required to change the P. C. of the curve from A to A', so that it shall terminate in a tangent $B'\ C'$ parallel to $B\ C$ and at a fixed distance from it.

The angle $B\ B'\ D = I$, the angle of intersection of the tangents.

We have $\sin B\,B'\,D = \dfrac{B\,D}{B\,B'}$, whence $B\,B' = \dfrac{B\,D}{\sin I}$.

$B\ B' = O\ O' = A\ A'$, the required distance to move the P. C. of the curve either backwards or forwards, according

as the required tangent is within or without the given tangent.

Substituting $A\ A'$ for $B\ B'$ we have $A\ A' = \frac{B\ D}{\sin I}$.

In the figure the required tangent is within the given

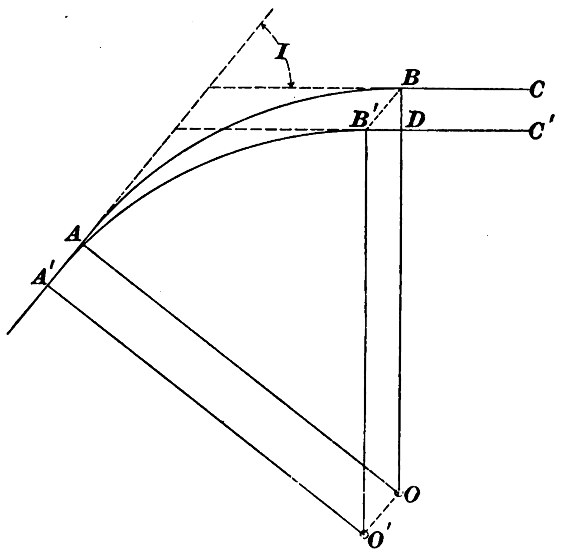


FIG. 361.

tangent. Let the intersection angle be 68° and the distance $B\ D = 40$ feet. Sin $68° = .92718$, whence $A\ A' = \frac{40}{.92718} =$ 43.14 feet.

That is, the P. C. of the required curve must be moved backwards 43.14 feet from the P. C. of the given curve.

1423. Problem II.—To change the point of compound curvature, the P. C. C., so that the second curve shall terminate in a tangent parallel to a given tangent, and at a given distance from it.

Case I. When the second curve is of shorter radius than the first curve:

Let $A\ B\ D$, Fig. 362, be a compound curve terminating

in the tangent $D\,H$, and let it be required to change the P. C. C. from B to some point E, so that the curve shall terminate (as shown in the figure) in a tangent $F\,G$, parallel to and at a given distance $H\,G$ from $D\,H$. To determine the point E (the new P. C. C.) the angle $E\,L\,F$ must be determined, and substituted for the known angle $B\,K\,D$. From C, the center of the larger curve, let fall upon $F\,G$ the perpendicular $C\,G$. From K and L let fall upon $C\,G$ the perpendiculars $K\,M$ and $L\,N$. Call the longer radius $C\,B$, R; the shorter radius $K\,D$, r; the distance $I\,F$ or its equal $H\,G$, D; the angle $B\,K\,D$ or its equal $K\,C\,M$, x, and the required angle $E\,L\,F$ or its equal $L\,C\,N$, y. Then,

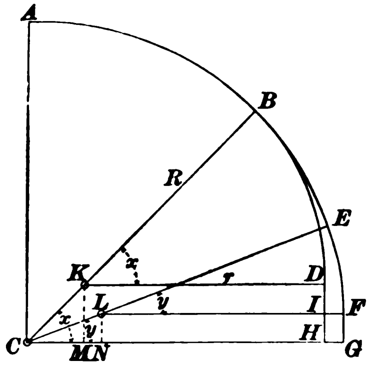


FIG. 362.

$$\cos y = \frac{(R-r)\cos x + D}{R-r}. \qquad \textbf{(99.)}$$

That is, *the distance $I\,F$ or $H\,G$ measured rectangularly between the two tangents, being added to the difference of the radii times $\cos x$, and the result divided by the difference of the radii, will give the cosine of the angle $E\,L\,F$, or y, to be turned on the smaller curve.*

Subtracting the angle y from the angle x, will give the angle $B\,C\,E$, to be added to the larger curve; and dividing this angle by the degree of curvature in $A\,B$ we find the distance from B to E, the required P. C. C.

If $E\,F$ be the second curve located, and the required tangent lies *within*, i. e., $D\,H$ is the required tangent, it is evident that instead of advancing on the curve $A\,B$, we must retreat on it to find the required P. C. C. Accordingly, we subtract D instead of adding, as in the preceding case.

EXAMPLE.—$A\,B$, Fig. 362, is a 4° curve to the right, located and compounding at B into a 7° curve, the latter being continued through an angle of 38°. At the P. T. we find that the proper tangent is 46 ft.

to the left, i.e., without the actual tangent, so that the curve will be *thrown out* to meet the required tangent. How far must the 4° curve be *continued?*

SOLUTION.—The radius of a 4° curve is 1,432.69 ft.; the radius of a 7° curve is 819.02 ft., hence, $R - r = 613.67$ ft. The cosine of 38° = .78801. Substituting known quantities in formula **99**,

$$\cos y = \frac{(R-r)\cos x + D}{R-r} = \frac{613.67 \times .78801 + 46}{613.67} = .86296.$$

Hence, angle $y = 30° \ 21'$. Subtracting this angle from 38° 00′, there remains a difference of 7° 39′, which must be added to the 4° curve. 7° 39′ reduced to decimal form is 7.65° ÷ 4 gives 1.9125 stations = 191.25 feet, which must be added to the 4° curve to reach the correct P. C. C. Ans.

In the above example, it is evident that, had the required tangent been within the given tangent, it would have been necessary to move the P. C. C. backwards instead of advancing it. This will increase the angle y of the second curve, and, consequently, its cosine will be reduced. The distance D will, therefore, be subtracted and the formula will read,

$$\cos y = \frac{(R-r)\cos x - D}{R-r}. \qquad \textbf{(100.)}$$

1424. Problem II.—Case II. When the second curve is of longer radius than the first curve:

Let $A\,B\,F$, in Fig. 363, be a compound curve terminating in the tangent $F\,H$, and it is required to change the P. C. C. from B to some point E so that the curve shall terminate in the tangent $D\,G$ parallel to $F\,H$ and at a given distance $H\,G$ from it.

Let the required tangent $D\,G$ be without the given tangent $F\,H$. Calling the perpendicular distance $H\,G$ between the tangents D; the radius of the larger curve, R, and the radius of the smaller curve, r; the given angle $B\,O\,F$ of the second curve, x, and the required angle $E\,C\,G$ of the second curve y, we have, as in formula **100**,

$$\cos y = \frac{(R-r)\cos x - D}{R-r}.$$

That is, the distance $H\,G$, measured rectangularly between the two tangents, should be subtracted as in formula **100.**

It will be seen that the required tangent is without the given tangent, consequently, it will be necessary to move

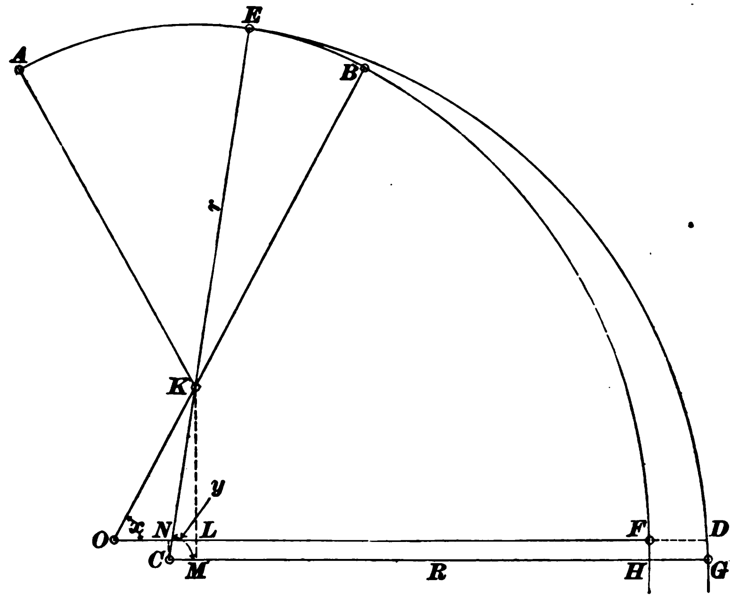


FIG. 363.

the P. C. C. backwards on the first curve, i. e., the angle of the first curve must be reduced.

EXAMPLE.—$A\ B$ is a 6° curve compounding at B into a 3° curve whose angle is 42° 30′, and whose tangent $F\ H$ is 52 ft. within the required tangent. How far backwards must the P. C. C. be moved?

SOLUTION.—The radius of a 6° curve is 955.37 ft., and the radius of a 3° curve is 1,910.08 ft.; hence, $R - r = 1{,}910.08 - 955.37 = 954.71$. Cos $x = \cos 42° 30' = .73728$. Substituting the known values in formula **100,** we have $\cos y = \dfrac{954.71 \times .73728 - 52}{954.71} = .68281$; whence, we find $y = 46° 56'$. Deducting 42° 30′ from 46° 56′, we have a difference of 4° 26′, which must be deducted from the first curve. 4° 26′ in decimal form is 4.433; 4.433 ÷ 6, the degree of the first curve, gives a quotient of .739 of a full station = 73.9 ft., the distance backwards from B to the correct P. C. C. at E. Ans.

If the required tangent were within the given tangent, the P. C. C. would be advanced and the angle y would be

reduced. The distance D would then be added and the formula would read

$$\cos y = \frac{(R - r) \cos x + D}{R - r}.$$

1425. Problem III.—To avoid obstacles on a curve: Let it be required to run a curve $A\,D\,E\,C$ between the points A and C, and suppose an obstacle lies directly in the path of the curve. The obstacle may be avoided by tracing a parallel curve $F\,G\,H\,I$, and from the stations on this parallel curve, the corresponding stations on the required

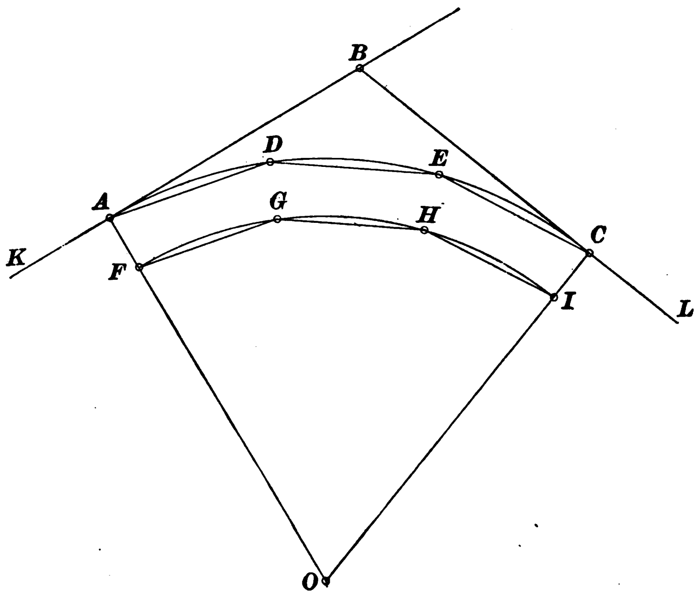


FIG. 364.

curve may be located. The process is as follows (see Fig. 364):

Having determined either P. C. or P. T., erect a perpendicular $A\,F$ to the tangent $A\,K$. Now, in the curve $F\,G\,H\,I$ it is evident that while the angle $A\,O\,C$ remains constant, the chords $F\,G$, $G\,H$, and $H\,I$ shorten as we approach the center O of the required curve. Let $A\,F =$

90 ft., and the radius $A\ O = 819$ ft. The chords of the required curve being 100 ft. in length, we have the following proportion: $O\ A : O\ A - A\ F :: 100 : F\ G$, the length of the chord of the parallel curve.

Substituting known values in the proportion, we have $819 : 729 :: 100 : F\ G$; whence, $F\ G = 89.01$ ft. Set up the instrument at F and trace the curve $F\ G\ H\ I$, setting a transit point at each station of 89.01 ft. Then set the transit at each of these points, as at G, and turn to a tangent of the curve as run. Then, turning a right angle, set a stake 90 ft. from G, locating the point D. In a similar manner locate each of the stations upon the required curve.

1426. Problem IV.—Having given two angles of intersection $D\ B\ E$ and $G\ F\ H$, and the distance $B\ F$ between the points of intersection (Fig. 365), it is required to find the radius of the easiest reverse curve which will unite

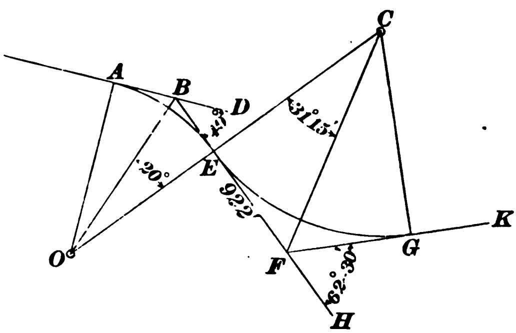


FIG. 365.

the tangents $A\ D$ and $F\ K$. The angle $D\ B\ E$ is equal to the angle $A\ O\ E$, half of which is $B\ O\ E$. The angle $G\ F\ H$ is equal to the angle $E\ C\ G$, half of which is $E\ C\ F$. Then, $(\tan B\ O\ E + \tan\ E\ C\ F) : \tan\ B\ O\ E :: B\ F : B\ E$. But $E\ F = B\ F - B\ E$. Reducing the proportion, we have

$$B\ E = \frac{\tan\ B\ O\ E \times B\ F}{\tan\ B\ O\ E + \tan\ E\ C\ F}.$$

Now, $B\ E$ is the tangent distance T of the curve $A\ E$, and

substituting known values in formula **91,** $T = R \tan \frac{1}{2} I$ (Art. **1251**), we have $B E = O E \tan B O E$; whence,

$$\text{radius } O E = \frac{B E}{\tan B O E}, \text{ and radius } C E = \frac{E F}{\tan E C F}.$$

EXAMPLE.—Let the angle $D B E$, Fig. 365, $= 40° 00'$, the angle $G F H = 62° 30'$, and the distance $B F = 922$ ft. Find the radius of the reverse curve.

SOLUTION.—The angle $B O E = \frac{1}{2} D B E = 20°$, and the angle $E C F = \frac{1}{2} G F H = 31° 15'$. Tan $20° = .36397$; tan $31° 15' = .60681$. The sum of these tangents is .97078, and we have the proportion .97078 : .36397 :: 922 : $B E$; whence, we find $B E = 345.68$ ft. Substituting the value of $B E$ in the formula, $T = R \tan \frac{1}{2} I$, we have $345.68 = O E \times .36397$; whence, we have radius $O E = \frac{345.68}{.36397} = 949.75$ ft. Substituting this value of R in the formula, $R = \frac{50}{\sin D}$ (Art. **1249**), we have $\sin D = \frac{50}{949.75}$, whence, $\sin D = .05264$ and $D = 3° 01'$, which, multiplied by 2, gives $6° 02'$, the required degree of the curve $A E$. To show the student that the curve $E G$ is of the *same degree* as the curve $A E$, we complete the calculation as follows: $B F = 922$ ft. and $E F = 922 - 345.68 = 576.32$ ft. Substituting the value of $E F$ in the formula $T = R \tan \frac{1}{2} I$, we have radius $C E = \frac{576.32}{.60681} = 949.75$ ft. Ans.

Substituting this value of R in the formula, $R = \frac{50}{\sin D}$, we have $\sin D = \frac{50}{949.75}$, whence $\sin D = .05264$, and $D = 3° 01'$; this, multiplied by 2, gives $6° 02'$, the required degree of the curve $E G$, which is the same as that of the curve $A E$. Ans.

1427. Problem V.—To find the radius of a curve which will be tangent to three given straight lines: Let $A B$, $B C$, and $C D$, in Fig. 366, be the given lines, then the required radius will be equal to

$$\frac{B C}{\tan \frac{1}{2} E B C + \tan \frac{1}{2} E C B}.$$

EXAMPLE.—Let $B C = 428$ feet, the angle $E B C = 23° 20'$, and the angle $E C B = 25° 20'$. Find the radius of the curve that will be tangent to $A B$, $B C$, and $C D$.

SOLUTION.—Tan $\frac{1}{2} E B C = .20648$, and tan $\frac{1}{2} E C B = .22475$. The sum of these tangents is .43123. Substituting these values in the

equation, radius $= \dfrac{B\,C}{\tan \frac{1}{2}\,E\,B\,C + \tan \frac{1}{2}\,E\,C\,B}$, we have radius $= \dfrac{428}{.43123}$, whence the required radius $= 992.51$ ft. Substituting this value of R in formula **89,** Art. **1249,** we have $\sin D = \dfrac{50}{992.51} = .05038$, and $D = 2^\circ\ 53.3'$, which, multiplied by 2, gives $5^\circ\ 46.6'$, the required degree

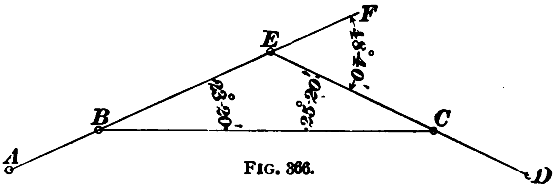


FIG. 366.

of the curve. Ans. The required degree of curve may be found by the following and simpler operation, viz.: Dividing 5,730 ft., the approximate radius of a 1° curve, by the given radius, 992.51 ft., we obtain a quotient of $5.773^\circ = 5^\circ\ 46.38'$, a result amply close for practical work. The angle of intersection $C\,E\,F$ is equal to $E\,B\,C + E\,C\,B = 48^\circ\ 40'$. Having found the radius and angle of intersection, the tangent distance is calculated by formula **91,** $T = R \tan \frac{1}{2}\,I$. (See Art. **1251.**)

1428. Problem VI.—To swing a tangent so that it will pass through a given point:

Let $A\,B$, in Fig. 367, be a curve whose tangent $B\,X$ passes through the point C, and it is required to swing the tangent $B\,X$ into the position $B'\,X'$, so that it shall pass through the point C'. With the instrument at B measure the angle $C\,B\,C'$. Divide this angle by the degree of the curve $A\,B$. The quotient will be the distance, in stations, which must be added to the curve $A\,B$ to bring the P. T. at B', and the tangent will pass through the required point C'.

EXAMPLE.—Let $A\,B$ be a 6° curve, and the angle $C\,B\,C' = 4^\circ\ 30'$. Swing the tangent $B\,C$ so as to pass through the point C'.

SOLUTION.—Reducing 4° 30′ to decimal form and dividing by 6, the degree of the curve $A\,B$, we have $\dfrac{4.5}{6} = .75$ of a full station $= 75$ ft., which we must add to the curve $A\,B$, bringing the P. T. at B', and the tangent $B'\,X'$ will pass through the point C'. Ans.

It will be evident that, had $B'\,X'$ been the given tangent and C the required point, it would have been necessary to

move the point of tangent B' backwards to B, i. e., to subtract 75 ft. from the given curve.

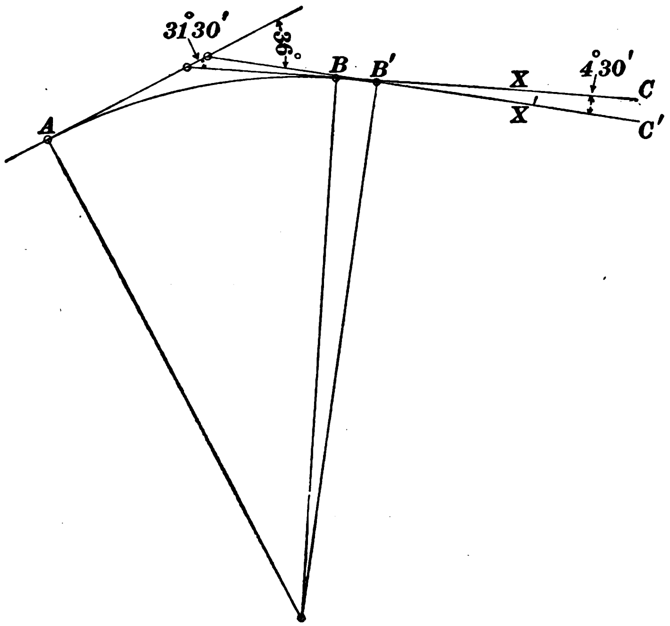


FIG. 367.

1429. Problem VII.—To find the distance across a river in a preliminary survey:

Let the line $A\,B$, Fig. 368, cross a river, too wide for direct measurement. With the instrument at A, sight to a flag held at B, and turn an angle $B\,A\,C = 1°$. Set a plug at C, opposite B in the line $A\,C$, and measure the distance $B\,C$.

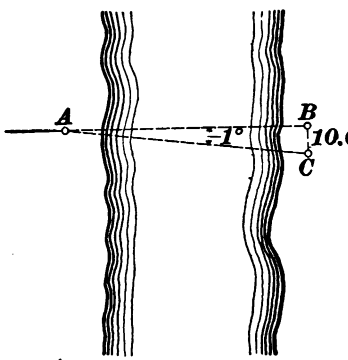


FIG. 368.

The required distance

$$A\,B = \frac{B\,C \times 100}{1.745}.$$

EXAMPLE 1.—If $B\,C = 10.6$ ft., how long is $A\,B$?

SOLUTION.—$A\,B = \dfrac{10.6 \times 100}{1.745} = 607.45$ ft. Ans.

EXAMPLE 2.—If $BC = 8.8$ ft., how long is AB?

SOLUTION.—$AB = \dfrac{8.8 \times 100}{1.745} = 504.3$ ft. Ans.

1430. Engineers' Field Books.—The problems given cover the cases which are liable to arise under ordinary conditions, and the explanations have been fully given. The engineer must necessarily carry a field book containing the usual tables of reference. All standard field books contain demonstrations of problems covering all those special cases which do not properly come within the scope of this work.

1431. Relative Position of Preliminary and Located Line.—The relative position of the preliminary and of the located line, where the work has been intelligently performed, is shown in the following sketch, Fig. 369, in which the preliminary line is shown in dotted and the location in full lines. The location is practically fixed by the preliminary line, leaving little to do but to run in the curves. The slight changes in the direction of the tangents and the degrees of the curves will be determined by an inspection of the contour map, which is the basis of every intelligent location.

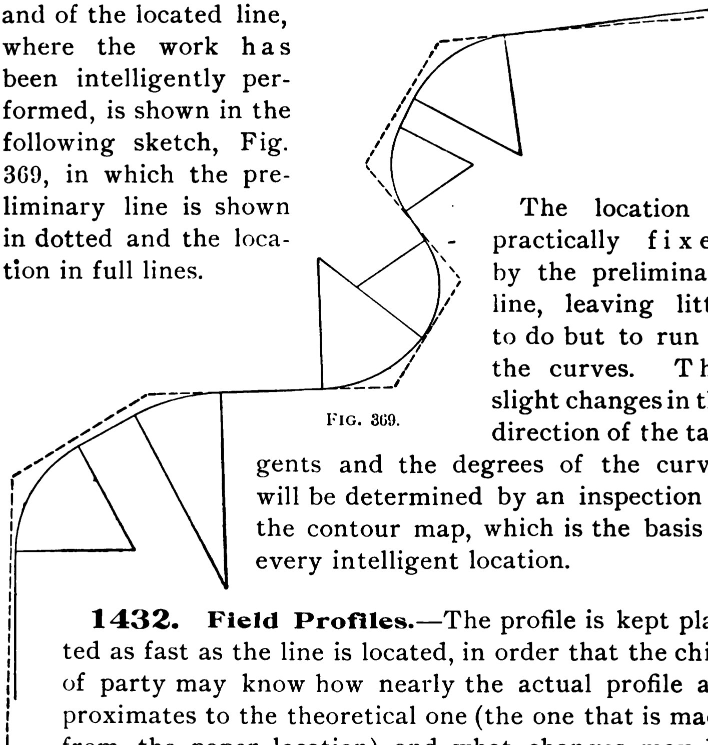


FIG. 369.

1432. Field Profiles.—The profile is kept platted as fast as the line is located, in order that the chief of party may know how nearly the actual profile approximates to the theoretical one (the one that is made from the paper location) and what changes may be necessary.

1433. Final Location.—After the right of way has been cleared, affording an unobstructed view of the ground, it will frequently be seen that slight changes in the located line will greatly reduce the cost of construction; and not until such changes are made will the engineer have made the *final location.*

None but experienced engineers can understand how a

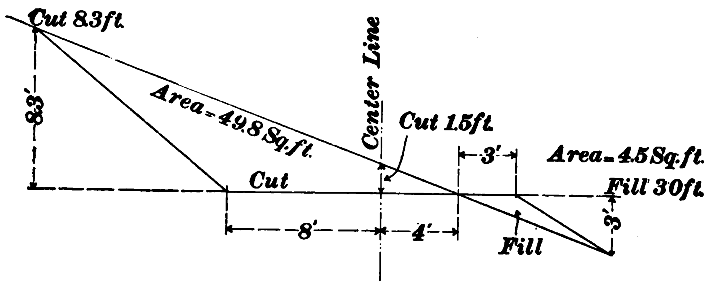


FIG. 370.

slight change in location, especially on a side hill line, can so greatly affect cost; and it is first cost which generally determines the success or failure of the enterprise.

The accompanying sketches will afford some light where it is oftenest needed. Fig. 370 is an example of poor location more often met with than that of any other kind, and yet one where a little conscientious work, together with common

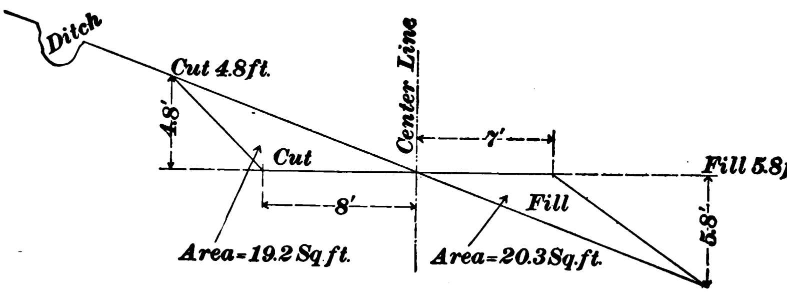


FIG. 371.

sense, would have produced amazing results, as shown in Fig. 371, which is decidedly good location. Side hills afford opportunity for almost the cheapest form of construction. A

grade line, i. e., where the grade coincides with the surface of the ground on the center line, as in Fig. 371, can, unless rock is encountered, be graded with pick and shovel alone, the men casting the material taken from the cut directly into and making the fill. The area of the cut in Fig. 370 is 49.8 sq. ft., while the area of the fill is but 4.5 sq. ft., leaving an excess of excavation of 45.3 sq. ft., or ten times the area of the fill. There is no way by which this excess of material can be utilized; it must, therefore, be wasted, as has been the labor of excavating it. By moving the center line 4 feet to the right, we obtain the cross-section shown in Fig. 371, in which the calculated areas of cut and fill are as follows: Cut, 19.2 sq. ft.; fill, 20.3 sq. ft.; a difference of less than 1 sq. ft., and the excess is on the right side, for a ditch should be made four feet from the top of the upper slope to prevent the washing down of the slope, and this material will more than equal the excess of the fill over the cut.

1434. Referencing Transit Points.—Having completed the final location, the points of curve and points of tangent must be referenced, and also intermediate points where a change of grade requires it. Such an intermediate point is shown in Fig. 372.

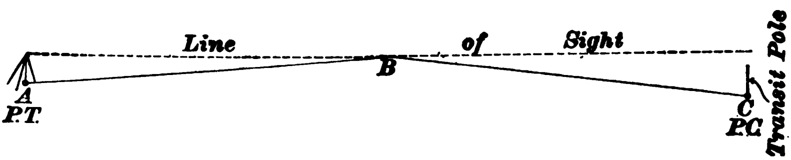


FIG. 372.

The line *A B C* from the P. T. at *A* to the P. C. at *C* is straight, but the transit pole at *C* can not be seen through the transit at *A* on account of the change of grade at *B*. It is, therefore, necessary to establish an intermediate point at *B* on the line *A B C*. The transit being set up at *B*, both P. T. and P. C. are in full view.

A good example of referencing is shown in Fig. 373. The reference points consist of plugs driven flush with the ground and protected by substantial guard stakes, which are

marked with the letters *R. P.* Where the located line traverses timber or brushwood, the ordinary stakes on the center line should be replaced by much larger ones. They are best cut from saplings about 3 feet in length and from $2\frac{1}{2}$ to $3\frac{1}{2}$ inches in diameter. A place for the stake is made with an iron bar, and the stake driven at least one foot in the ground with a sledge hammer. Special care is taken in

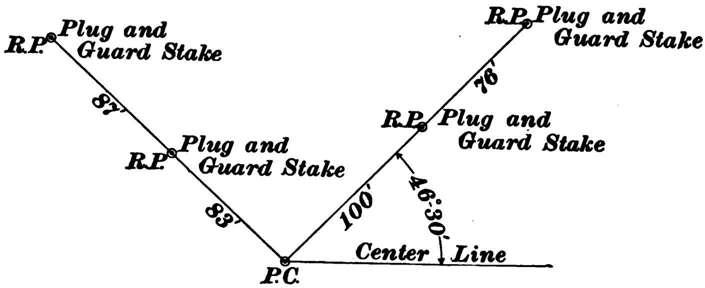


FIG. 373.

guarding points of curve and tangent. While the right of way is being cleared a man is detailed to look after the stakes and hubs on the center line, as many will be disturbed or torn out of the ground while hauling logs and timber from the right of way. When the clearing and burning is completed, the center line should be rerun, restoring all lost or disturbed stakes. Transit points, if well set, will rarely be disturbed. When the center line is restored the transit points are referenced. A little care and judgment will enable the engineer to select reference points which will remain undisturbed during the work of construction. Where the work is heavy these points will be further removed from the center line than at points where the work is light.

When the grading is completed, the original points of curve and tangent can be restored and the center line run in from both ends of the curve. Any small error in alinement due to inaccuracies in the measurement of the original line will then be thrown on the middle of the curve, where

they will not in any way affect the excellence of the work, and the tangents will remain unchanged.

1435. Final Levels.—While the transit points are being referenced, the leveler takes the *final levels*, reading all turning points with the target and correcting all *bench marks*. He need not hurry, as accuracy is all important. An error in final levels is unpardonable, as the work of construction is based upon them. Most errors in field work are directly chargeable to carelessness. A bench mark is established at each bridge site, and at all points of the line where permanent structures, such as arch culverts, trestles, water tanks, stations, etc., are to be built. The *final profile* is platted from these levels and the grade line drawn in pencil. The points of curve and tangent are marked in small circles on one of the horizontal lines at the bottom of the profile. That portion of the line corresponding to tangents is drawn in a full line, and the balance, representing the curves, in broken line. The stations of the points of curve and tangent are also numbered on the profile.

The compensations for curvature are then calculated, and the final grade line drawn in ink.

1436. Compensation for Curvature.—From .03 to .05 ft. per degree is the compensation or reduction in grade, made for the added resistance due to curvature, i. e., where the established grade for tangents is 1 per cent., the grade on a 6° curve, allowing a compensation of .03 ft. per degree, would be $1.00-(.03 \text{ ft.} \times 6)=.82$ per cent. Where a compensation of .05 ft. per degree is made, the grade on a 6° curve would be $1.00-(.05 \times 6)=.70$ per cent.

1437. Final Grade Lines.—The establishing of *final grade lines* is illustrated in Fig. 374, where the uncompensated grade is 1.3 per cent., and the compensation for curvature as shown in the final grade line is .03 ft. per degree.

The location notes for the line included in the diagram are as follows:

Stations.	Intersection Angles.
52 + 00	End of Grade.
49 + 75 P. T.	
44 + 25 P. C. 9° R.	49° 30′
42 + 00 P. T.	
37 + 50 P. C. 6° L.	27° 00′
33 + 00 P. T.	
29 + 00 P. C. 8° R.	32° 00′
27 + 00	Beginning of Grade.

The profile is made to standard scales, viz., horizontal 400 ft. = 1 in.; vertical, 20 ft. = 1 in. The elevation of the grade at Sta. 27 is fixed at 120 ft., and at Sta. 52 at 152.5 ft., giving between these stations an actual rise of 32.5 ft. and an uncompensated grade of 1.3 per cent. These grade points we mark on the profile in small circles. The total curvature between Sta. 27 and Sta. 52 is 108½°. The resistance due to each degree of curvature being taken as equivalent to an increase of .03 ft. in grade, the total resistance due to 108.5° is equal to .03 ft. × 108.5 = 3.255 ft., and is equivalent to adding 3.255 ft. to the actual rise between Sta. 27 and Sta. 52. Hence, the total theoretical grade between these stations is the sum of 32.5 ft., the actual rise, and 3.255 ft. due to curvature, which is 35.755 ft. Dividing 35.755 by 25, the number of stations in the given distance, we have $\frac{35.755}{25} = + 1.4302$ ft., the grade for tangents on this line. The starting point of this grade is at Sta. 27. The P. C. of the first curve is at Sta. 29, giving a tangent of 200 ft. = 2 stations. As the grade for tangents is + 1.4302 ft. per station, the rise in grade between Stas. 27 and 29 is 1.4302 × 2 = 2.8604 ft. The elevation of the grade at Sta. 27 is 120 ft., and the elevation of grade at Sta. 29 is 120 + 2.8604 = 122.8604 ft., which we record on the profile as shown in Fig. 374, with the

rate of grade, viz., + 1.4302 written above the grade line. The first curve is 8°, and as the compensation per degree is .03 ft. for 8°, or a full station, the compensation is .03 ft. × 8 = .24 ft. The grade on the curve will, therefore, be the tangent grade minus the compensation, or 1.4302 − .24 ft. = + 1.1902 ft. per station. The P. C. of this curve is at Sta. 29, the P. T. at Sta. 33, making the total length of the curve 400 ft. = 4 stations. The grade on this curve is + 1.1902 ft. per station, and the total rise on the curve is 1.1902 × 4 = 4.7608 ft. The elevation of the grade at the P. C. at Sta. 29 is 122.8604; hence, the elevation of grade at the P. T. at Sta. 33 is 122.8604 + 4.7608 = 127.6212 ft., which we record on the profile together with the grade, viz., + 1.1902, written above the grade line. The P. C. of the next curve is at Sta. 37 + 50, giving an intermediate tangent of 450 ft. = 4.5 stations. The grade for tangents is + 1.4302 ft. per station; hence, the total rise on the tangent is 1.4302 × 4.5 = 6.4359 ft. Adding 6.4359 ft. to 127.6212 ft., we have for the elevation of grade at Sta. 37 + 50, 134.0571 ft., which we record on the profile, together with the rate of grade for tangents.

The next curve is 6° and the compensation in grade per station is .03 ft. × 6 = .18 ft. The grade on this curve will, therefore, be 1.4302 − .18 = 1.2502 ft. per station. The length of the curve is 450 ft. = 4.5 stations, and the total rise in grade on this curve is + 1.2502 ft. × 4.5 = 5.6259 ft. The elevation of the grade at Sta. 37 + 50, the P. C. of the curve, is 134.0571. The elevation of the grade at Sta. 42, the P. T., is, therefore, 134.0571 + 5.6259 = 139.683 ft., which we record on the profile together with the rate of grade on the 6° curve, viz., + 1.2502. The P. C. of the next curve is at Sta. 44 + 25, giving an intermediate tangent of 225 ft. = 2.25 stations. The total rise on the tangent is, therefore, 1.4302 × 2.25 = 3.21795 ft. The elevation of grade at the P. T. at Sta. 42 = 139.683; therefore, the elevation of grade at Sta. 44 + 25 = 139.683 + 3.21795 ft. = 142.90095 ft., which we record on the profile together with the grade, viz., + 1.4302. The last curve is 9° and the compensation in

grade per station is .03 ft. × 9 = .27 ft. The grade on 9° curve is, therefore, 1.4302 − .27 = 1.1602 ft. per station. The length of the curve is 550 ft. = 5.5 stations, and the total rise on the curve is 1.1602×5.5=6.3811 ft. The elevation of grade at Sta. 44 + 25, the P. C. of the 9° curve, is 142.90095; hence, the elevation of grade at the P. T., at Sta. 49 + 75, is 142.90095 + 6.3811 = 149.28205 ft., which we record on the profile together with the grade, + 1.1602. The end of the line is at Sta. 53, giving a tangent of 225 ft. = 2.25 stations. The rise on this tangent is 1.4302×2.25 = 3.21795 ft., which we add to 149.28205, the elevation of the P.T. at Sta. 49+75. The sum, 152.5 ft., is the elevation of grade at Sta. 52. The *sum* of the *partial grades* should equal the *total rise* between the extremities of the grade line.

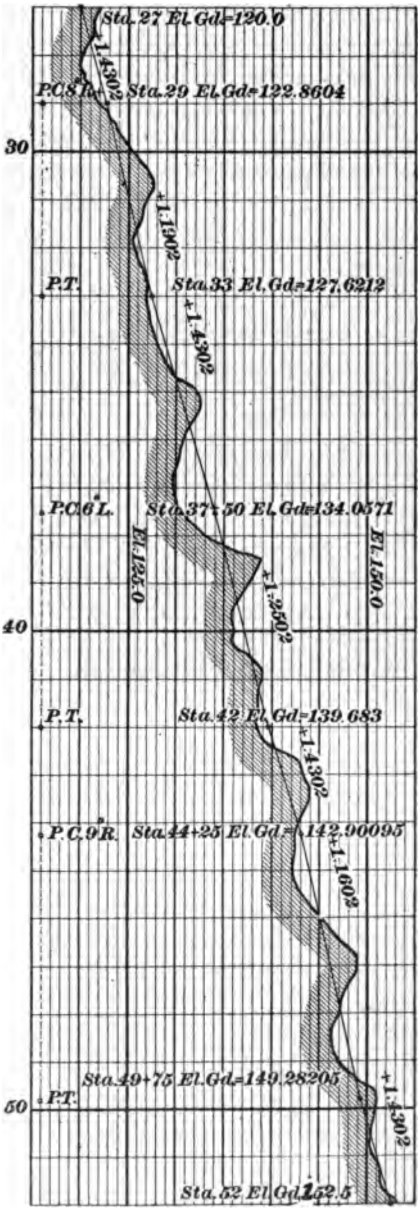


FIG. 874.

The points where the changes of grade occur are marked on the profile in small circles, which are connected by fine lines which represent the grade line. These points of change are projected on a horizontal line at the bottom of the profile. Those portions of this line representing curves are dotted, and those portions representing tangents are drawn full. The points of curve P. C. and P. T. are marked in small circles on this horizontal line, and lettered as shown in the figure.

Where the grades are light and the curves easy, there will *be no need of compensation* for curvature. Where the grades exceed .5 per cent. and the curves 5°, compensation should be made.

1438. Changing of Grade Lines.—Unforeseen difficulties sometimes arise during construction which warrant the changing of grade lines, but these occasions are rare. If the final grade line has been properly considered, it would better remain unchanged. The engineer should learn to make up his mind and stick to it.

1439. Vertical Curves.—Vertical curves are used to round off the angles formed by the meeting of two grade

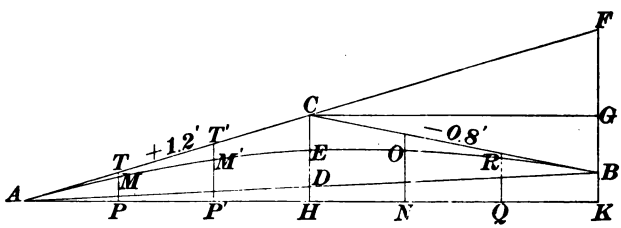


FIG. 375.

lines. Let $A\ C$ and $C\ B$, Fig. 375, be two grade lines meeting at C.

These grades are given by the *rise* per station in going in some particular direction. Thus, starting from A, the grades $A\ C$ and $C\ B$ may be denoted by g and g'; that is, the grade for any station on $A\ C$ is found by adding the

rate of grade g to the grade of the preceding station, and the grade for any station on $C\,B$ is found by adding the rate of grade g' to the grade of the preceding station. But $C\,B$ is a descending grade. Therefore, the rate g', to be added to each station, is a minus quantity and g' is negative.

The parabola furnishes a simple method of putting in a vertical curve.

1440. Problem.—Given the grade g of $A\,C$, Fig. 375, the grade g' of $C\,B$, and the number of stations n on each side of C to the tangent points A and B, to unite these points by a parabolic vertical curve:

Let $A\,E\,B$ be the required parabola. Through B and C draw the vertical lines $F\,K$ and $C\,H$, and produce $A\,C$ to meet $F\,K$ in F. Through A draw the horizontal line $A\,K$ and join A and B, cutting $C\,H$ in D. Then, if a represents the vertical distance of the first station M on the curve from the corresponding station T on the tangent, the vertical distance at the second station will be the square of 2, or $4\,a$, and at the third station the square of 3, or $9\,a$, and at B, which is $2\,n$ stations from A, the vertical distance to the curve will be the square of $2\,n$ or $4\,n^2\,a$; that is, $F\,B = 4\,n^2\,a$, and $a = \frac{F\,B}{4\,n^2}$. To find a, it will first be necessary to find $F\,B$. This may be done by means of the following formula, in which g and g' are the grades mentioned in Art. **1439**, and n is the number of stations between A and C:

$$a = \frac{g - g'}{4\,n}. \qquad \textbf{(101.)}$$

Having determined the value of a, the distances of the several stations in $A\,C$ and $C\,B$ from the curve, viz., a, $4\,a$, $9\,a$, $16\,a$, etc., are readily known. Let T and T' be the first and second stations on the tangent $A\,C$, and if from T and T' perpendicular lines $T\,P$ and $T'\,P'$ be drawn to the horizontal line $A\,K$, $T\,P$, the height of the first station T above A, equals g, and $T'\,P'$ equals $2\,g$, and for succeeding stations we shall find the heights $3\,g$, $4\,g$, etc. We have

already found $T\,M = a$, $T'\,M' = 4\,a$, etc. The heights of the curve above the level of A will, therefore, be as follows: At M, height $= T\,P - T\,M = g - a$; at M', height $= T'\,P' - T'\,M' = 2\,g - 4\,a$, and at E, height $= C\,H - C\,E = 3\,g - 9\,a$, and for succeeding points $4\,g - 16\,a$, etc. To find the grades for the curve at successive stations from A, that is, the amount which must be added to the grade or height of one station to equal the grade of the following station, we must subtract each height from the next following height. Thus, calling the height of A 0, we have $(g - a) - 0 = g - a$, the height of M above $A\,K$, called the grade of M; $(2g - 4\,a) - (g - a) = g - 3\,a$, which must be added to the grade of M to find the grade of M'; $(3\,g - 9\,a) - (2\,g - 4\,a) = g - 5\,a$, which must be added to the grade of M' to find the grade of E. The succeeding quantities are $(4\,g - 16\,a) - (3\,g - 9\,a) = g - 7\,a$, $(5\,g - 25\,a) - (4\,g - 16\,a) = g - 9\,a$, and $(6\,g - 36\,a) - (5\,g - 25\,a) = g - 11\,a$. The successive grades or additions for the vertical curve, Fig. 375, are $g - a$, $g - 3\,a$, $g - 5\,a$, $g - 7\,a$, $g - 9\,a$, and $g - 11\,a$.

In finding these grades, strict regard must be paid to the algebraic signs. The results are then general.

1441. EXAMPLE 1.—Let the number of stations on each side of C, Fig. 375, be 3, and let $A\,C$ be an ascending grade of 1.2 feet per station, and $C\,B$ a descending grade of .8 ft. per station. Assume the elevation of the grade at Sta. A to be 120 feet, and find the grade at each station from A to B.

SOLUTION.—Here $n = 3$, $g = +1.2$ ft., and $g' = -.8$ ft. Substituting known values in formula **101**, $a = \frac{g - g'}{4\,n}$, we have $a = \frac{1.2 - (-.8)}{4 \times 3} = \frac{2.0}{12} = .1666$ ft., and the grades from A to B will be

		Heights of Curve above A.
$g - a = 1.2 - .167 =$	1.033 ft.	1.033 ft.
$g - 3a = 1.2 - .500 =$	.700 ft.	1.733 ft.
$g - 5a = 1.2 - .833 =$	.367 ft.	2.100 ft.
$g - 7a = 1.2 - 1.166 =$	.034 ft.	2.134 ft.
$g - 9a = 1.2 - 1.500 = -$	.300 ft.	1.834 ft.
$g - 11a = 1.2 - 1.833 = -$	.633 ft.	1.201 ft.

Since the elevation of the grade at Sta. A, Fig. 375, is 120.00 feet, the grades for the following stations of the vertical curve will be:

	Station.	Elevation of Grade.	Station.	Elevation of Grade.
Ans.	A	120.000 ft.	O	122.134 ft.
	M	121.033 ft.	R	121.834 ft.
	M'	121.733 ft.	B	121.201 ft.
	E	122.100 ft.		

EXAMPLE 2.—Let $A\ C$, Fig. 376, be a descending grade of 1.0 ft. per station, and $C\ B$ an ascending grade of .5 ft. per station. Let the vertical curve include 2 stations each side of C. Find the grade at each station from A to C.

SOLUTION.—Here $g = -1.0$ ft., $g' = +.5$ ft., and $n = 2$. Substituting

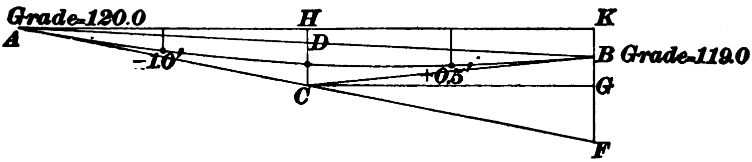


FIG. 376.

these values in formula **101**, $a = \frac{g - g'}{4\,n}$, we have $a = \frac{-1.0 - (.5)}{8} = \frac{-1.5}{8} = -.1875$, and the four grades required will be:

$$
\text{Ans.}\begin{cases}
g - a = -1.0 - (-.1875) = -1.0 + .1875 = -.8125 \text{ ft.}\\
g - 3a = -1.0 - (-.5625) = -1.0 + .5625 = -.4375 \text{ ft.}\\
g - 5a = -1.0 - (-.9375) = -1.0 + .9375 = -.0625 \text{ ft.}\\
g - 7a = -1.0 - (-1.3125) = -1.0 + 1.3125 = +.3125 \text{ ft.}
\end{cases}
$$

It will be seen that after finding the first grade, the succeeding grades are found by a continual subtraction of $2\ a$. Thus, in the first example, each grade after the first is .333 ft. less than the preceding grade. In the second example, a is a negative quantity, and each grade after the first is .375 ft. greater than the preceding grade.

The grades in the foregoing examples are calculated for whole stations, and are sufficient for all purposes except for track laying or ballasting, when grade stakes on the vertical curve should be driven at intervals of 25 feet, and the grades must be calculated for these sub-stations. To do this, let g

and g' represent the grades for a sub-station of 25 feet, and n the number of such sub-stations on each side of the intersection of the grade lines.

EXAMPLE.—In the last example divide the curve into sub-stations of 25 ft. each. Assume the grade at A to be 120 feet, and find the grade at each sub-station.

SOLUTION.—Here $g = -.25$ ft., $g' = +.125$ ft., and $n = 8$. Substituting these values in formula **101**, $a = \frac{g - g'}{4n}$, we have $a = \frac{-.25 - (.125)}{32} = \frac{-.375}{32} = -.01172$. The first grade is, therefore, $g - a = -.25 - (-.01172) = -.23828$. Each subsequent grade increases $2a$; that is, $-.02344$, and we have the following: Grade at Sta. 2 = $-.21484$; Sta. 3, $-.19140$; Sta. 4, $-.16796$; Sta. 5, $-.14452$; Sta. 6, $-.12108$; Sta. 7, $-.09764$; Sta. 8, $-.07420$; Sta. 9, $-.05076$; Sta. 10, $-.02732$; Sta. 11, $-.00388$; Sta. 12, $+.01956$; Sta. 13, $+.04300$; Sta. 14, $+.06644$; Sta. 15, $+.08988$; Sta. 16, $+.11332$.

The distance $A\,B$, Fig. 376, is 400 feet divided into 16 sub-stations of 25 feet each. Since the grade of A is 120.0 feet, the grades of the following stations will be:

Ans.

Stations.	Grades.	Stations.	Grades.
A	120.000	9	118.699
1	119.762	10	118.672
2	119.547	11	118.668
3	119.355	12	118.688
4	119.187	13	118.731
5	119.043	14	118.797
6	118.922	15	118.887
7	118.824	16, B	119.000
8	118.750		

The purpose served by vertical curves will be at once apparent to the student. The sudden and severe stress upon the rolling stock caused by passing from one grade to another results in great harm to rolling stock and much discomfort to passengers. Vertical curves should always be put in the grade during construction. Where the meeting grades are very slight, no curve is necessary.

1442. Preliminary Estimates.—Having established the final grades, the next work of the engineer is the preliminary estimate. This estimate gives in detail the approximate quantities of all material to be handled in the work of

construction, and of all probable cost attending such work. Work and materials to be furnished, together with the prices ruling in the locality where the work is to be done, are classified as follows:

1443. Classification of Preliminary Estimates.—

1. Clearing per acre		$20.00.
2. Excavation....	Earth, per cubic yard......	20c.
	Loose rock, per cubic yard..	40c.
	Solid rock, per cubic yard...	80c.
Overhaul exceeding 1,000 feet, per cubic yard		1c.
3. Trestling.	Piles, per lineal foot........	25c. to 30c.
	Frame, per 1,000 ft. bd. measure, Ga. pine	$35.00.
4. Masonry..	1st-class rock-face range work, per cubic yard......	$10.00 to $12.00.
	2d-class good lime mortar rubble, per cubic yard....	$8.00.
	Dry rubble, per cubic yard..	$4.00 to $4.50.
	Riprap per square yard, in place	$1.50 to $2.50.
5. Bridging.	Wooden...................	
	Iron and steel..............	

Classification not only affects price, but quantity. Cuts in solid rock, which are the most costly, stand at a slope of $\frac{1}{4}$ horizontal to 1 vertical, while earth ordinarily requires a slope of 1 horizontal to 1 vertical, and sometimes as flat a slope as $1\frac{1}{2}$ horizontal to 1 vertical. All materials excavated, and all masonry, are estimated by the cubic yard. Trestling is estimated by the 1,000 feet, board measure, and piling by the lineal foot. Wooden bridges, of moderate span, are sometimes estimated at a fixed price per 1,000 feet for lumber, and a fixed price per lb. for iron, but generally a special estimate is made for each bridge. The cost of bridges increases rapidly as the span increases. In metal bridges the cost will increase about as the square of the

span, i. e., if one bridge has twice as great a span as another, the first will cost the square of 2 or 4 times as much as the second.

1444. Quantities.—The material to be handled in grading the roadbed is generally estimated by *level cuttings*, which process assumes that the cross-section surfaces are

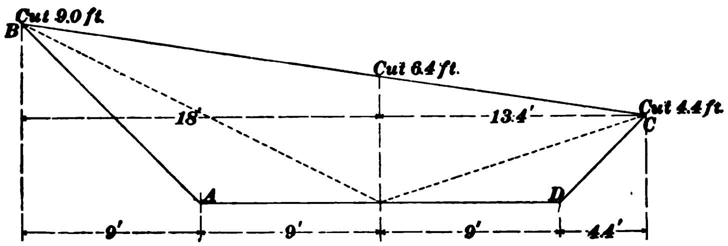


FIG. 377.

level, and the areas are calculated from the *center cuts* and *fills*. Let Fig. 377 represent the actual cross-section at a given station, and Fig. 378 the cross-section based upon the center cut. The area of the section $A\ B\ C\ D$ in Fig. 377, calculated from the actual cross-sections, is 160.78 sq. ft. The area of the section $A'\ B'\ C'\ D'$, in Fig. 378, calculated

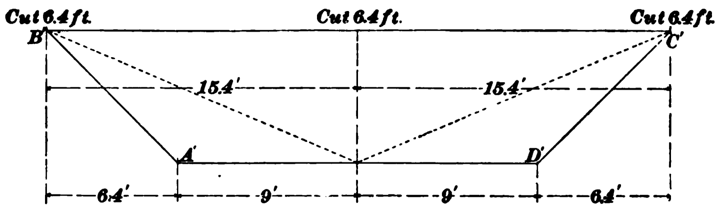


FIG. 378.

from a level section, with the same center cut, viz., 6.4 feet, is 156.16 sq. ft., giving a discrepancy of 4.62 sq. ft.; that is, the area of the section, calculated by level cuttings, is 4.62 sq. ft. less than the area calculated from the actual cross-sections. This deficiency is about 3 per cent., but where the slope is very steep, the difference increases rapidly. As the invariable custom is to add 10 per cent. to the estimated

TABLE OF LEVEL CUTTINGS.

Roadway 18 ft. Wide; Slopes 1 Horizontal to 1 Vertical.

For Single-Track Excavation.

Depth of Cut in Feet.	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.	cu. yd.
0	0	6.7	13.5	20.3	27.3	34.3	41.3	48.5	55.7	63.0
1	70.4	77.8	85.3	92.9	100.6	108.3	116.1	124.0	132.0	140.0
2	148.1	156.3	164.6	172.9	181.3	189.8	198.4	207.0	215.7	224.5

cost, such addition will fully cover any deficiency resulting from table calculations. Where time is not an object, it is good practice to take the slopes with a clinometer and plat them on cross-section paper. The estimate thus obtained will be a close approximation to the actual quantities handled in the work of construction. For work in the Northern and Middle States the following rates of slope are standard: For embankments, $1\frac{1}{2}$ horizontal to 1 vertical; for earth cuts, 1 horizontal to 1 vertical, and for rock cuts, $\frac{1}{4}$ horizontal to 1 vertical. In Western and Southern States it is the usual custom to give to cuts the same slope as to embankments, viz., $1\frac{1}{2}$ horizontal to 1 vertical.

1445. Trautwine's Engineers' Pocket Book contains complete tables of level cuttings for standard widths of roadway, both single and double track. The slopes are given for earthwork, both excavation and embankment. The quantities are calculated for sections 100 feet apart. If the sections are taken oftener than each 100 feet, the quantities will be proportionally less. The table of Level Cuttings shows the arrangement for single-track excavation, roadway 18 feet wide, slopes 1 horizontal to 1 vertical.

The use of this table is explained as follows: Suppose the center cut at Station 10 is 1.5 ft. and the center cut at Station 11 is 3.0 ft. The sum of these two center cuts, $1.5 + 3.0 = 4.5$ ft. The mean or average center cut at these stations is, therefore, $\frac{4.5}{2} = 2.25$ ft. As the nearest tenth is always used, we will call the average cut between Stations 10 and 11, 2.2 ft.

Referring to the table, we find in the column headed *depth of cut in feet*, the figure 2, and on the same horizontal line, under the column headed .2, we find 164.6, which is the number of cubic yards of material to be excavated between Stations 10 and 11.

The quantities are given for center cuts from .1 foot to 60 feet. For cuts greater than 60 feet, the quantities are calculated for only even feet.

1446. Sections.—The line is divided into lengths of one mile each, called *sections*, which are numbered in regular order, the first mile of the line being section 1, the second mile section 2, and so on. At the division points, i. e., where one section ends and another begins, posts are set up with boards attached, facing in both directions, with the number of the section towards which they face written in large figures. See Fig. 379.

The section boards enable one to readily locate any particular part of the line.

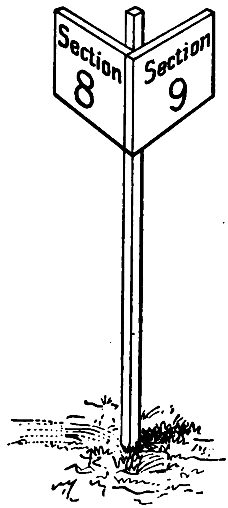


FIG. 379.

1447. Right of Way.—Before construction can be commenced, the right of way must be secured, a matter always attended by more or less difficulty. The standard width of right of way is 100 feet, though, in some cases, but 4 rods or 66 feet is adopted, with additional widths wherever needed.

Where the local needs for the road are great, and the enterprise popular, much right of way is often donated, a nominal sum, usually one dollar, being paid as consideration. The ordinary mode of securing right of way is by direct purchase. The company employs an agent specially fitted for his business, who makes the most advantageous bargains possible with the different owners. When there is failure to agree on price, a common alternative is to leave the question to three arbitrators, each of the parties to the transaction choosing one and agreeing together upon the third. The arbitrators unite upon a valuation which the contracting parties have agreed to accept. Occasionally, an owner, taking advantage of the situation, attempts extortion, in which case the only recourse is to the *law of eminent domain.* Articles of condemnation are taken out and appraisers appointed by the court, who fix the amount of

compensation. The process is always attended by expense, delay, and vexation, and should only be a last resort.

1448. Right of Way Maps.—A careful survey is made of each separate piece of property bought for right of way or station grounds, and stone corners established for future reference. These surveys should be platted in a "right of way" book in the same order in which they occur on the line, and a copy of the contract for and description of the property written on the same page or that adjoining the plat. The plat should specify content, boundaries, corners, and any information which may be of future use. A copy of the contract and a tracing of the plat is delivered to the person or persons from whom the property is bought.

1449. Specifications.—Specifications describe the manner in which the work of construction is to be conducted and the materials to be used in structures.

Specifications are of two kinds; viz., *general*, those describing the different general classes of work, and *special*, those referring to a particular structure or other work requiring special plans or processes. In this work only general specifications will be given.

X., B., & C. R. R.

GENERAL SPECIFICATIONS FOR GRADING AND BRIDGING.

1. **Clearing.**—The surface is to be cleared the full width of right of way and such additional width as the engineer in charge shall direct, of all trees, bushes, and other perishable matter.

2. **Grubbing.**—In cuttings, and in embankments where the fill is two feet and less, all trees and stumps between the slope stakes must be grubbed out; where the fill is more than two feet, all trees and stumps must be cut down even with the surface of the ground. No payment will be made for grubbing.

3. **Grading.**—Under this head will be included all excavations and embankments required for the formation of the roadbed, side tracks, and station grounds; the foundation pits for bridges, culverts, and cattle-guards; the cutting of ditches and drains contiguous to the roadbed; all excavations and embankments in constructing farm and highway crossings, and in the changing of channels for streams.

4. **Borrow Pits.**—The embankment shall be constructed from material borrowed from the right of way. No embankment shall be constructed from material deposited by casting without special permission of the engineer in charge. If borrow pits are required outside the right of way, they shall be procured by the railroad company.

5. **Provision for Settling.**—Cuts and ditches shall be measured in excavation; all other work shall be measured and paid for in embankment. The embankments shall be made from 5 to 10 per cent. higher than the established grades. This additional percentage is an allowance for shrinkage, and shall be fixed by the resident engineer. No allowance for such shrinkage shall be made in the estimate.

6. **Single-Track Work.**—In single-track work the roadway shall be eighteen feet in width at sub-grade in cuts, and fourteen feet in width on embankments. The side slopes of earth cuts shall be one horizontal to one vertical, and of rock cuts one-quarter horizontal to one vertical, unless otherwise specified by the engineer in charge. The side slopes for embankments shall be one and one-half horizontal to one vertical. A berme six feet in width shall be left between the slope stakes and the edge of the borrow pits.

7. **Double-Track Work.**—In double-track work the roadway shall be twenty-eight feet in width at sub-grade in cuts, and twenty-four feet in width on embankments. Side slopes of earth cuts shall be one horizontal to one vertical; of rock cuts, one-quarter horizontal to one vertical, unless otherwise specified by the engineer in charge. The side slopes for embankments shall be one and one-half horizontal

to one vertical. A berme six feet in width shall be left between the slope stakes and the edge of the borrow pit.

8. **Borrow Pits.**—A space three feet in width shall be left between the borrow pits and the right-of-way lines. The slopes of borrow pits shall not be steeper than one and one-half horizontal to one vertical, and shall generally be of such depth as will secure proper drainage.

9. **Ditches.**—All excavations shall be finished with side ditches of such dimensions as the engineer shall direct, and to prevent the washing of slopes, ditches shall be cut on the up-hill side, such ditches to be not less than four feet from the top of the slope.

10. **Excavation.**—The classification for all excavated material will be as follows:

Earth will include clay, sand, gravel, loam, decomposed rock, and slate, and all other matters of an earthy kind, however hard, stiff, or compact, and all boulders containing less than three cubic feet each.

Loose rock will include all stone and detached rock found in separate masses, containing not less than three cubic feet nor more than one cubic yard; also, all slate, coal, or other rock, soft or loose enough to be removed without blasting, although blasting may be resorted to; also, stratified limestone in layers eight inches thick and under, separated by strata of clay.

Solid rock will include all rock in masses of more than one cubic yard which can not be removed without blasting.

11. **Foundation excavation** above the general water level at the time shall be excavated by the contractor and paid for at his grading prices. The residue of foundation work will be executed by the contractor, and paid for by the company at actual cost, with ten per cent. added for contractor's supervision, use of tools, etc. The price per yard bid for masonry will include centerings, scaffoldings, and all other expenses connected with the work, excepting the foundation work above specified.

12. **Tunnel Excavation.**—The price for tunnel excavation will include all excavation between the portals of the tunnel proper, and within the area of the cross-section, as determined by the engineer, and it will include also all temporary supports, scaffolding, etc. The area of the cross-section for tunnel excavation will be measured six inches outside the wall and arch, and all excavation outside of this cross-section will not be paid for unless in the opinion of the engineer such irregularities could not be prevented by the exercise of proper care and judgment in excavating, and paid for at such prices as the engineer shall determine.

13. **Masonry.**—Masonry shall be built according to plans furnished by the engineer, and estimated and paid for by the cubic yard. Masonry in which mortar is required shall be kept well wet while being laid, and every stone shall be clean and thoroughly wet when laid. Arches shall be built on substantial centers extending the entire length of the arch, and the mode of construction, as well as the plan, shall be approved by the engineer. Centers shall not be removed or loosened without the direction of the engineer. The price per yard shall in all cases include the furnishing of centers, scaffolding, and all other cost and expense incidental to the completion of the work. All joints of face walls of masonry laid in mortar shall be suitably pointed, and the work finished to the satisfaction of the engineer.

Tunnel Masonry.—The masonry for tunnels and all bridge piers and abutments shall be of *Rock Face Range Work.* All of the arch stones shall be well and smoothly cut on the beds, ends, and face, and shall be laid so that their beds shall be at right angles to the tangent of the curve. The beds of each stone shall have full and solid bearings, and the jcints shall be close and straight.

Walls and arches shall be laid in regular courses of uniform thickness. No course shall be less than four inches in thickness. The faces shall be *Rock Face* with edges pitched to straight and true lines.

The vacancies behind tunnel walls and above tunnel arches

shall be filled with concrete or dry packing, at the discretion of the engineer. All packing must be well rammed in place as the work progresses.

First-Class Masonry.—In all first-class masonry the stones of each course shall be gauged to the same thickness, and after each course is laid and grouted or filled with mortar, the tops of the stones shall be dressed so as to bring the top of the course to a common level.

Stretchers shall be not less than three feet in length, with bed not less than sixteen inches. Headers shall be not less than eighteen inches in width, nor less than three times the thickness of the course in length. Stretchers and headers should be in the proportions of 3 to 1. All face stones shall be dressed full to the square for their entire length and width, and shall be so cut and laid as to have a full bearing for their entire bed. All joints shall be close and straight, and be so broken as to make a perfect bond.

Backing shall be of good-sized and well-shaped stones and so dressed that each stone shall lie firmly on its bed. The backing shall be laid with reference to each succeeding course, affording good header bearers and so bonding the whole into one solid mass. All stones shall be laid in mortar, and if the engineer shall so direct, the vertical joints shall remain open until the course is finished. All unfilled parts of the wall shall be filled with mortar or grout. The tops of the walls shall be coped with large broad stones, not less than three feet in length, the same to be well-dressed on the top and ends, and all face joints pointed with good mortar.

Culvert Masonry.—Arched and box culverts shall be built of good-sized and well-shaped stones, and laid *dry* unless otherwise directed by the engineer in charge. Stones shall be straightened on faces and ends with fair proportion of headers, and laid with joints broken so as to form a compact and substantial body. Covering stones shall be of such length and thickness as the engineer in charge shall direct.

The top courses of wing walls shall be of wide stones with good joints, so as to form a good and smooth coping.

14. **Pavement.**—Between the side walls and at the ends of culverts and bridges where required, paving will be laid of good smooth stones set on edge and well fitted, so as to make a close, smooth surface. Paving shall be of such thickness as the engineer shall direct, and it shall be secured at ends and sides by curb stones not less than two feet in depth. To prevent undermining, broken stone shall be deposited outside the curbing. Paving will be paid for by the cubic yard.

15. **Mortar and grout** shall be made of clean sharp sand and fresh slacked lime, in the proportions of one part of lime to two of sand. Mortar shall be thoroughly mixed and allowed to stand until all particles of lime are thoroughly slacked. Hydraulic cement to be substituted for lime at the discretion of the engineer, the difference in actual cost to be refunded to the contractor. The proportion of the ingredients of mortar and grout may be varied at the discretion of the engineer.

16. **Protection.**—When required by the engineer, embankments will be protected by cribbing built of round logs and filled with stone, or riprap laid with beds at right angles to the slope of embankment, affording a close and generally smooth surface. Contractors shall hold themselves in readiness to perform such work with promptness and dispatch. Cribbing will be paid for by the lineal foot, and riprap by the cubic yard—both to be measured in place.

17. **Piling.**—Piles shall be of white or burr oak, long leaf pine, or other suitable timber, sound and without loose or rotten knots. They shall measure not less than seven inches in thickness at the small end, and average not less than eleven in thickness. The bark must be removed before driving.

18. **Driving.**—Piles must be driven at the places staked out for them by the engineer in charge, and they must be

driven, if the engineer so desires, to such a depth that a hammer weighing 2,000 pounds, falling upon the pile from a height of twenty feet, will not sink the pile more than one inch.

19. **Timber.**—All timber shall be of sound, straight-grained white or long leafed southern pine or other suitable timber, free from rotten knots or shakes, and with no sap extending more than two inches from any edge.

20. **Framing.**—The framing shall be done in the most workmanlike manner and in accordance with plans furnished by the engineer.

21. **Inspection.**—The kind and quantity of all material in the work shall be subject to the approval of the engineer in charge. Timber shall be estimated in place and paid for by the thousand feet, board measure. All iron used in structures will be paid for by the pound.

22. **Monthly Estimates.**—During the progress of the work, on or about the first of every month a monthly estimate shall be made of the kind, quality, amount, and value of work done during the preceding month, eighty-five per cent. of which value will be paid to the contractor on or about the fifteenth of said month, and when the work is completed and accepted there shall be a final estimate made by the engineer of the quantity, character, and value of the entire work, according to the terms of the contract, and the balance, after deducting the several monthly payments, and upon the contractor giving release to the company from all claims or demands whatsoever, will be paid in full.

23. The **contractor** shall render an account monthly, through the proper superintending engineer, of any extra work which he may have been authorized to do; and to prevent disputes hereafter, it is hereby understood that no bills for extra work will be allowed unless authorized and ordered *in writing* by the engineer in charge, and the bill for said extra work presented at the end of the month in which the work was done, and approved by said engineer.

24. During the progress of the work and until it shall be completed and accepted by the company, it shall be the duty of the contractor, at his own expense, to sufficiently guard and protect the same by barriers, fences, or otherwise, so as to prevent travelers or other persons from sustaining injury to themselves or property by falling into any excavation or running over any dangerous fill or embankment, or over or against stumps, timber, or any material, or in any other way whatsoever; and in blasting stone, the contractor shall use the utmost precaution and care to avoid injuring persons or property, and the contractor shall save and keep the company free and harmless from the payment of any damage for injury to persons or property arising from any malfeasance or negligence of the contractor or of any of his sub-contractors, agents, or servants.

25. The **contractor** shall not let or transfer his contract or any part of it, or withdraw his personal attention therefrom, without the consent of the engineer.

26. The **contractor** shall put on and maintain night forces at such points and to such extent as the engineer shall direct.

27. In all disputes the decision of the engineer shall be final.

28. By **engineer** is meant the **chief engineer.**

1450. Advertising for Work.—A classified estimate is made of the amount of work in each section, and the road is advertised for contract. These advertisements name a date for the opening of bids. Contractors are provided with a printed copy of the general specifications and of the estimated quantities in each section, and are allowed to take such notes as they may require from the map and profile. In walking over the line they can readily locate any particular section from the *section boards.*

1451. Reservations.—The company should invariably reserve the right to reject any or all bids, in order that

they may shut out irresponsible men or prevent a combination of contractors from charging exorbitant prices for work.

1452. Bond.—Contractors should be required to furnish a bond signed by two responsible parties to insure the proper fulfilment of their contract. This bond is usually to the amount of ten per cent. of the estimated cost of the work undertaken. The contract specifies the date on or before which the contractor shall complete the work, and often specifies a forfeit to be imposed in case of any default on the part of the contractor to fulfil the conditions of his contract.

RAILROAD CONSTRUCTION.

1453. The Engineer Corps.—The engineer corps in charge of construction differs in organization from that in charge of location. In general, when construction is commenced, it is prosecuted with vigor throughout the entire line, and, as the work requires constant inspection, the force of engineers is considerably augmented.

1454. Subdivisions of the Line.—The entire line is divided into sections of about 30 miles each, called **divisions,** each division being placed in charge of a **division engineer.** The divisions are further divided into lengths of about 10 miles each, called **residencies.** Each residency is placed in charge of a **resident engineer.**

1455. The Division Engineer, His Authority and Duties.—The division engineer has general charge of an entire division and is directly accountable to the **chief engineer,** from whom he receives general orders relating to the work of his division. He should go over his entire division twice each week, giving particular directions to the resident engineers for the conduct of the work and maintaining a general supervision of the whole. His office should, if possible, be so situated as to afford prompt mail service. Telegraphic communication with the chief engineer is important, though not always possible. Plans of all the important structures on a division, excepting large bridges, are made at the division office and forwarded to the chief engineer for approval. The monthly estimates made by the resident engineers of his division are inspected by the division engineer, a careful record of them kept at his office, and forwarded by him to the chief engineer for approval.

1456. The Resident Engineer, His Corps, and Their Duties.—The corps in charge of each residency, comprises the resident engineer, instrument man, rodman, tapeman, and axman. The resident engineer has immediate charge of all work on his residency, a profile of which is given him with the grade lines drawn upon it, with the gradients and compensation for curvature clearly stated. At each watercourse shown in the profile, a brief description is written, giving the character and dimensions of the structure required at that place. He is given a copy of the specifications which are to guide him in making a proper inspection of the work. A suitable office is provided him at or as near the middle of his residency as possible, and furnished with drawing table, drawing materials, field books, pads, and official stationery. A horse and strong two-seated buckboard are an important part of his outfit, especially when in thickly settled country, where the line of road is readily accessible from public highways.

The first duty of the resident engineer is to check the alinement and levels on the line of his work, transferring bench marks from trees or rocks, which are liable to be disturbed, to permanent objects far enough from the center line to be outside of the slope stakes.

1457. Setting Slope Stakes.—His next work is setting slope stakes, commonly called **cross-sectioning,** which consists of setting stakes in the ground at the points which will mark the *top of the cut* or *foot of the slope* of the finished roadway. The following dimensions are suitable for cross-section stakes: Length, 2 feet; width, 2 inches, and thickness, 1 inch. They should be planed on one side to admit of easy marking, and sharpened for driving. In a country of average smoothness, the level, rod, and tape are used in locating slope stakes; but in very rough localities, the **Y** level is used to carry the continuous line of levels, while the side elevations, from which the slope stakes are located, are determined by means of the hand level and rods.

The process of setting slope stakes is illustrated in Figs. 380 and 381. In Fig. 380, the elevation of the grade is 103.0 feet. The height of instrument *A* is 97.5 feet, and, hence, the instrument is 5.5 feet below grade. The rod reading at the center line is 6.0 feet, hence, the surface of the ground at the center line is below grade, i. e., there must be a fill, the amount of which is made up of two quantities, viz.: First, the difference between the elevation of grade and the height of instrument; and, second, the rod reading at the center line.

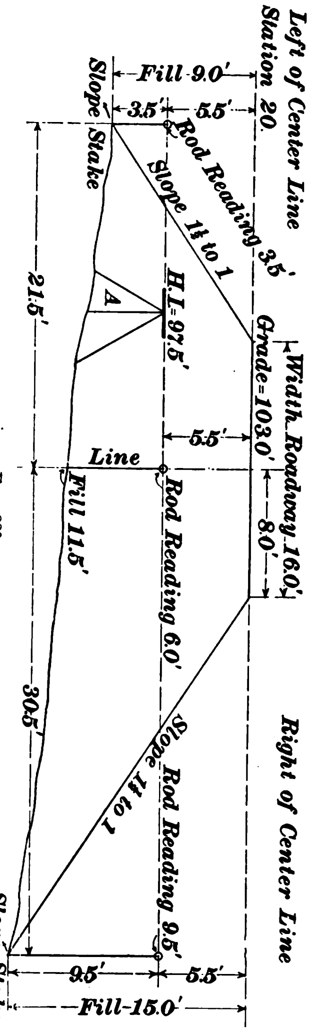


FIG. 380.

The first of these quantities is 5.5 feet, the second 6.0 feet, and their sum, 11.5 feet, is the amount of the fill at center. If this cross-section is taken at a full station, there will already be a stake in place, and the *fill* is marked on the back of the stake F. 11.5. If the section is taken at an intermediate point, i. e., a sub-station, say 20 + 50, the center line is located by ranging in from the stakes at the regular stations and the stake is marked 20 + 50 on one side and the fill, F. 11.5, on the other side, and the stake driven with the numbering facing Station 20. The *slope stakes* are located by holding the leveling rod where, in the judgment of the rodman, the foot of the slope of the completed embankment will be. In Fig. 380,

the rod reading at the right of the center line is 9.5 feet, which, added to 5.5 feet, the difference between the height of instrument and grade, gives a fill of 15 feet. The natural slope of earth is one and one-half horizontal to one vertical, called a slope of 1½ to 1. Therefore, in a fill of 15 feet, the foot of the slope will be 1½ times 15, which is 22.5 feet from the top of the slope, to which must be added one-half the width of the roadway, viz., 8 feet, making 30.5 feet from the center line. The rod is accordingly held at 30.5 feet from the center line. If the rod reading at this distance is the same, i. e., 9.5 feet, it marks the foot of the slope, and a stake marked F. 15.0 is driven in the place of the rod. Usually the rod will not read exactly the same when held at the calculated distance, and another calculation will be necessary, two trials generally proving sufficient. In Fig. 381, the right slope stake is fixed in the same way. The left slope stake is

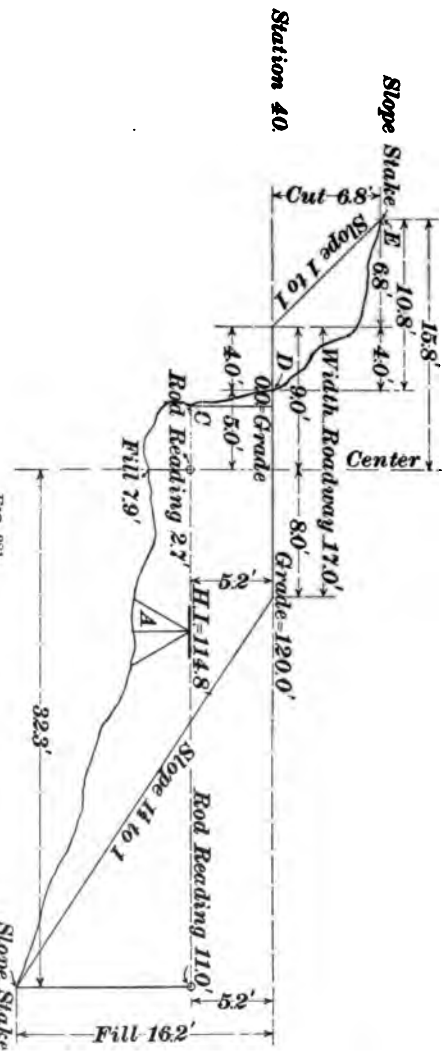


FIG. 381.

located by means of rods and a hand level. First, a point C is found where the line of sight from the level A cuts the surface of the ground. A cross-section rod, which is similar to a transit pole, is held at this point, which is 5.2 feet below grade. At 5.2 feet above C, a rod is held in a horizontal position, and the point D where it meets the ground marked by a stake. This point is at grade, i. e., where the plane of grade cuts the ground. The stake is marked by two ciphers *0.0*, and its location recorded in the note book. By means of the rods, the left slope stake at E is located. As the left slope is in excavation, the left half of the roadway will be one foot greater in width than the right half, viz., 9 feet. As the slopes in excavation are but one horizontal to one vertical, called a slope of 1 to 1, the distance of the slope stake from the center line is the sum of

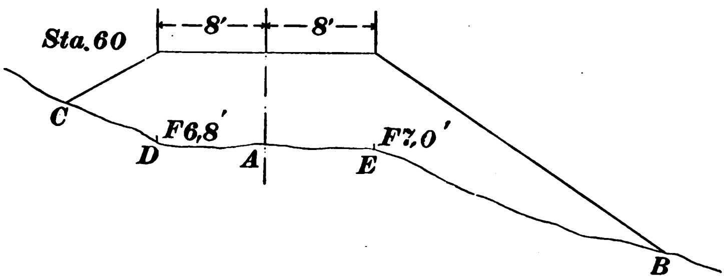


FIG. 382.

one-half the width of the roadway, viz., 9 feet, and the depth of cutting. In Fig. 381, the cut is 6.8 feet; consequently, the slope stake is set at $9 + 6.8 = 15.8$ feet from the center line. When the cross-section is irregular, intermediate readings are taken as shown in Fig. 382.

In this section, besides finding the center fill, 6.8 feet at A, and the fill 14.4 feet at foot of right slope at B, and a fill of 3.8 feet at C at foot of left slope, intermediate readings are taken at D and E where the slope of the cross-section changes. These readings are recorded in the note books, but no stakes are driven at the points of change of slope.

1458. Form of Cross-Section Notes.—The levels are carried continuously from bench mark to bench mark, the level notes being recorded on the left-hand page of the note book and the cross-section notes recorded on the right-

Station.	Rod Reading.	Height Inst.	Center Elevation.	Grade.	Center Cut.	Center Fill.	Left Line.	Right Line.
20	6.0	97.5	91.5	103.0		11.5	$\frac{\text{F. }9.0}{21.5}$	$\frac{\text{F. }15.0}{30.5}$
40	2.7	114.8	112.1	120.0		7.9	$\frac{\text{C. }6.8}{15.8}$ $\frac{0.0}{5.0}$	$\frac{\text{F. }16.2}{32.3}$
60						6.8	$\frac{\text{F. }3.8}{13.7}$ $\frac{\text{F. }6.8}{8.0}$	$\frac{\text{F. }7.0}{8.0}$ $\frac{\text{F. }14.4}{29.6}$

hand page. The above form of cross-section notes is simple and complete, and contains the notes for Figs. 380, 381, and 382.

The cross-section notes are recorded in the form of fractions, the amount of cut or fill being the numerator of the fraction, and the distance of the slope stake from the center line, called the **side distance**, being the denominator.

It will be seen in comparing the notes for Station 20 with Fig. 380 that the rod reading at the center stake is 6.0 feet, which gives a center fill of 11.5 feet. The figure shows at the foot of the right slope a rod reading of 9.5 feet. The instrument man instead of determining the elevation of the ground at this point by subtracting the rod reading from the height of instrument and then calculating the fill by subtracting the elevation of the surface of the ground from the calculated grade for that station, calculates the fill in this way. If a rod reading of 6.0 feet gives a fill of 11.5 feet, a rod reading of 9.5 feet must require as *much more* filling than 11.5 feet as 9.5 feet is *greater* than 6.0 feet. The

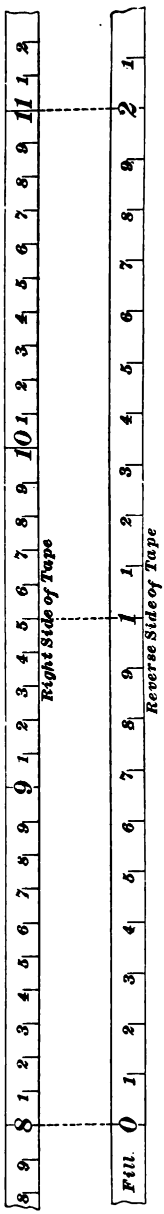


FIG. 383.

difference 9.5 − 6.0 = 3.5 feet; 11.5 + 3.5 = 15.0 feet, i. e., a rod reading of 9.5 feet requires a fill of 15.0 feet.

In the notes for Sta. 60, corresponding to Fig. 382, it will be observed that the intermediate readings taken at D and E are recorded in the same order in which they are taken. The calculations of the side distances are simple problems in mental arithmetic, and, with a little practice, they can be made with great rapidity. A tape especially adapted to cross-section work is graduated on both sides, one side giving the varying fills from 1 foot to 28 feet, and the other side being graduated to feet and tenths of a foot. Fig. 383 illustrates the principle upon which the tapes are made.

As shown in the figure, the *eight-foot* mark on the right side of the tape corresponds with the *zero* mark on the reverse side. The reason for this is that, whatever the fill, the slope stake must be placed at least eight feet from the center line in order to afford sufficient width for the roadway. Each division representing tenths of feet of filling is equivalent to $1\frac{1}{2}$ tenths of feet of lineal measurement, that is, a fill of 1 foot, as marked on the reverse side of the tape, corresponds to the division 9.5 feet on the right side of the tape. In using the tape, a man stands at the center stake holding the tape case. The rodman holds the end of the tape besides carrying the rod. The man at the center stake *lines in* the rodman, that is, he places him as nearly at *right angles* to the center line as he can estimate by the eye. The rodman

first holds the rod at where he judges will be the foot of the slope. The instrument man calculates the fill and calls the amount of the fill to the tapeman, who finds on the reverse side of the tape the numbers corresponding to the given fill, and holds the tape at that point on the center stake, causing the rodman to approach or recede from the center line according as his calculation has differed from the true one. Again, a rod reading is taken and the amount of the fill called out, and the corresponding fill being found on the tape, the rodman is checked again by the level. Two trials, unless the slopes are very irregular, will generally be sufficient.

1459. Clearing.—All trees, logs, and bushes are cleared from the right of way. Ordinarily, this work is let by contract at a fixed price per acre to experienced woodsmen. A skilful axman will fall and trim more trees in one day than five inexperienced men, and the work will be better done. The resident engineer should require the contractor to clear the right of way immediately after his taking charge of the work, as the work of staking out must be deferred until after the clearing is completed. As all timber on the right of way belongs to the railroad company, the resident engineer should require the contractor to avoid unnecessary destruction of merchantable timber while clearing the right of way. Timber suitable for cross-ties should be worked up at once, the ties being piled in safe places and in such form as will admit of rapid seasoning. Logs large enough for boards and square timber are piled well out of reach of the work of construction. Clearing will cost from $20 to $50 per acre.

1460. Grubbing.—**Grubbing** includes the removing of all trees and stumps lying within the slope stakes in cuttings and in embankments where the fill is two feet or less. Formerly all trees and stumps were grubbed by digging about the stump and exposing the roots, which were cut off with an ax. After the large roots were severed, a long

lever was used to complete the work by overturning the stump. A better method succeeded this very slow and expensive work of grubbing. The trees were left standing and as soon as the large roots were cut, horsepower was employed as follows: A strong rope was fastened to the trunk high above the ground. A strong team (often two teams) were then hitched to the rope at a safe distance from the tree. The leverage gained was great, and the tree could often be overset with half or even less than half the grubbing that was required by the older process. In modern practice dynamite is almost exclusively employed. The trees are first felled and their trunks and branches removed. A round-pointed bar of steel 2 inches in diameter is driven at an angle beneath the stump, penetrating far enough to bring the explosive directly beneath the stump. The bar is then removed, and the hole loaded with dynamite, precisely as in blasting rock. A little experience will enable one to gauge the amount of the charge. The execution of the powder is thorough, generally blowing the stump, together with the roots, completely out of the ground and splitting the stump into several pieces, which greatly facilitates the work of handling them. In grubbing stumps with dynamite, the gain in first cost over other methods is great, but the gain in time is greater still.

Grubbing is sometimes paid for by the acre, oftener by the stump, and in some cases the cost of grubbing is included in the price paid for excavation.

As stated in Art. **1433,** the clearing of the right of way will often afford opportunity for slight changes in the line which will considerably reduce the cost of construction. It is important that the work of cross-sectioning be completed at the earliest possible date after construction has commenced, as the demands upon the engineer's time multiply when construction is well under way. Where the line traverses open and timbered country in about equal proportions, the cross-sectioning on the open stretches can be pushed while the clearing is being done; in this manner the work can be kept well in hand.

CULVERTS.

1461. Classification of Culverts.—Culverts are of three classes, viz., **box, tile,** and **arched.** The dimensions of a culvert will depend upon the amount of water to be discharged. This amount will depend upon the area and character of the water shed. The engineer can approximately determine this area either from an inspection of county maps or from personal examination of the country. Local records of high water will be of great service to him. Culverts should always be made large enough to meet the requirements of the greatest freshets. The following formula is used by some engineers in determining the area of a culvert opening :

$$A = c\sqrt{M}, . \qquad \textbf{(102.)}$$

in which A is the area of the opening of the culvert in square feet, M is the drainage area in acres, and c the variable coefficient depending upon the nature of the country, 1.6 being used for compact hilly ground, 1 for comparatively level ground, and being raised to 4 for abrupt rocky slopes.

For example, under average conditions, a drainage area of 200 acres with a coefficient of 1.6 will give the following cross-section area for a culvert:

$$A = 1.6\sqrt{200} = 22.62 \text{ sq. ft.}$$

In this situation a double-box culvert would be suitable, with openings three feet in width and four feet in height, separated by a wall two feet in thickness.

1462. Box Culverts.—Foundations will be prepared as follows: Excavate a pit, including the *entire area* of the opening and the side walls, to a depth of 1 foot. Cover this area with a paving of stones set on edge 1 foot in depth, with a curb two feet in depth at each face of the drain, and start the walls on this paving. The paving, after being laid, should be well rammed, in order to afford a firm foundation for the superstructure. If the fall of the drain does not exceed 9 inches, drop the upper end to a level with the lower end. When the fall is greater than 9 inches,

make a sufficient number of drops of 9 inches each to equal the difference in the elevation of the two ends of the drain.

At each drop, place a cross-sill 2 feet in depth. Box culverts are not made of *greater span* than *3 feet.* When a wider opening is required, a *double-box culvert* is built with a division wall 2 feet in thickness.

A general plan for a single-box culvert is shown in Fig. 384. The distance marked 10 ft. is termed the *height of the embankment at center line.*

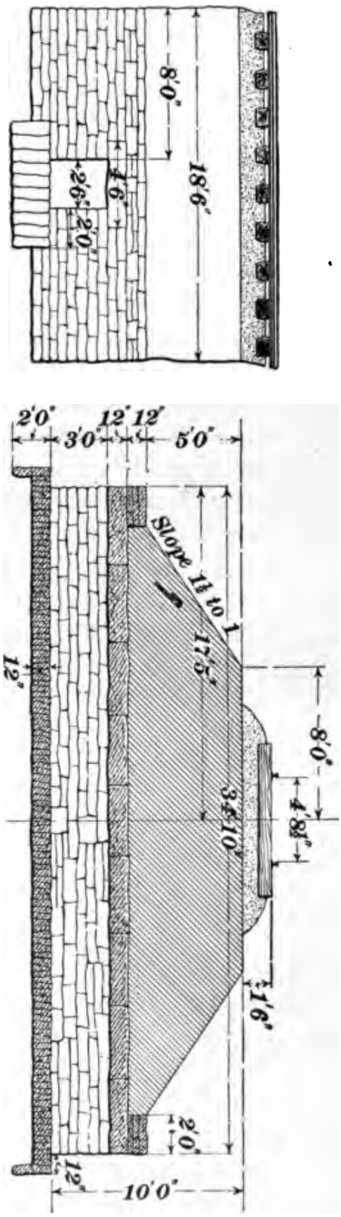


FIG. 384.

Box culverts are generally constructed of dry rubble masonry. The stones in the abutments (also called *side walls*, and having a height of 3 ft., in Fig. 384) should be of good size, faced with beds roughly dressed and laid with joints well broken. Binders reaching through from face to face of wall must be used in sufficient numbers to insure a compact and stable structure. Covering flags (4 ft. 6 in. wide and 1 ft. thick, in Fig. 384) must be of compact stone free from seams

and with faces dressed so as to insure a complete covering. Mortar is used at the discretion of the engineer in charge. The parapet, 1 ft. thick, is laid on the covering flags.

In soft, marshy soils, a 1-foot paving will not afford a secure foundation, especially if quicksand be present. A pit 2 feet in depth and filled with stone, leaving only sufficient depth for the 1-foot paving, and well rammed, will, together with the paving, bear any ordinary box culvert. In wet, boggy soils, a secure foundation may be obtained by excavating a pit of double the area of the superstructure to the depth of 2 feet and laying a course of logs of uniform size over the entire bottom of the pit. A layer of broken stone is then spread over the logs of sufficient depth to secure a uniformly level surface. The paving is laid upon this surface, and the foundation is then in readiness for the abutments.

Rule I.—***To Lay Out a Box Culvert on the Ground.***—*Take the height of the top of the parapet from the height of the embankment at the center line. With this difference as height of embankment, find the side distance as in setting slope stakes. To these side distances add 18 inches, and* ***if the embankment is 10 feet in height or over, add 1 inch*** *on each end for each foot in height above the parapet.*

The covering flags are 1 foot in thickness and the parapet 1 foot in height, making the top of the parapet 2 feet above the top of the abutment or side walls. The height of the parapet is, therefore, the height of side walls + 2 feet. The thickness of side walls must never be less than 2 nor more than 4 feet in thickness.

Rule II.—***To Find the Length of Wing Walls.***—*Add to the height of side walls the thickness of the covering flags. One and a half times this sum plus 2 feet will give the distance from the* ***inside face of the side wall*** *to the end of wing.*

The wing walls (marked 8 ft. long, in Fig. 384) *must be parallel* to the center line of the road.

EXAMPLE.—The roadway is 16 feet in width, the height of the embankment at the center line is 22 feet, the abutments are 4 feet in height, the covering flags 1 foot thick, the parapet is 1 foot in height; what is (*a*) the distance from the center line to end of abutment wall, and (*b*) the distance from face of abutment wall to end of wing wall?

SOLUTION.—(*a*) Applying rule **I**, we have $22 - (4 + 2) = 16$.

$$16 \times 1\tfrac{1}{2} + 8 + 1 \text{ ft. } 6 \text{ in.} + 1 \text{ ft. } 4 \text{ in.} = 34 \text{ ft. } 10 \text{ in.} \quad \text{Ans.}$$

(*b*) Applying rule **II**, we have $4 + 1 = 5$. $5 \times 1\tfrac{1}{2} + 2 = 9$ ft. 6 in. Ans.

1463.—Tile Culverts.—In localities where stone is scarce and costly, **culvert pipe** furnishes an economical and efficient substitute. Culvert pipe is made of clay, which is subjected to a high degree of heat, when it is known as vitrified pipe. The manufacture of culvert pipe is carried on extensively in most of the chief American cities, the range in sizes being sufficient to meet all requirements. The pipes vary in length from 24 to 30 inches, and in diameter from 12 to 24 inches. They are fitted with socket or bell joints similar to those on cast-iron water pipes.

The thickness of the shell is $\frac{1}{12}$ the diameter of the pipe, and the width of the socket $\frac{1}{6}$ the diameter. The pipe is laid on a concrete foundation with sufficient fall to prevent water from standing in the pipes. A shallow pit is dug to receive the concrete, the pipes being laid as soon as the concrete is in place and brought to a grade. The pipes are laid with joints of cement mortar, and covered with concrete to one-half their height; the latter are held in place by side boards, secured by banking with earth or by stakes driven in the ground. The concrete affords a secure foundation and prevents leaking at the joints, which is the chief cause of failure of pipe culverts with earth foundations.

The parapet walls are of rubble masonry laid in cement mortar, and carried far enough below the bottom of the pipe to prevent undermining. In alluvial soils, such as are traversed by many of our western lines, it is frequently necessary to carry the parapet walls to a depth of six and even eight feet to guard against the undermining of the embankment. The parapet walls need not be built until after the completion of the road, when the stone may be

hauled by construction trains, thereby saving the great cost of transporting building stone by teams. A general plan

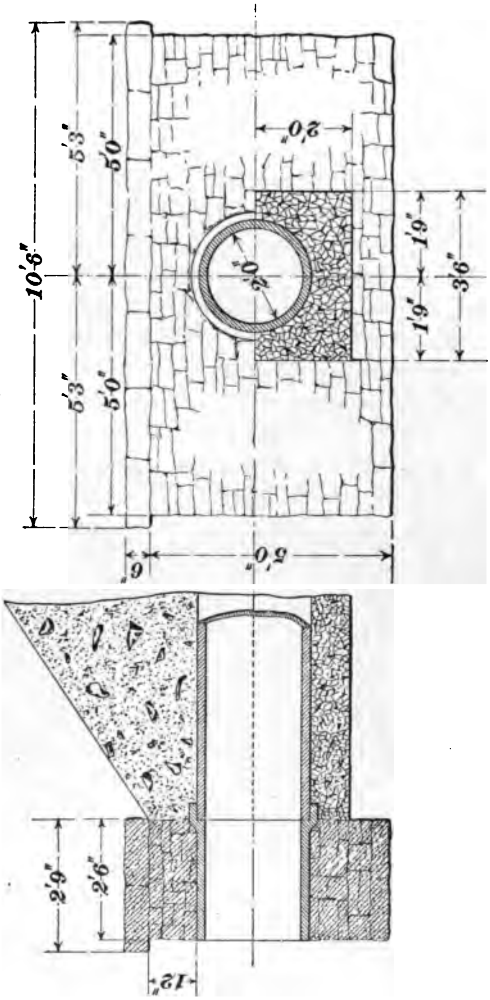


FIG. 385.

of pipe culvert is given in Fig. 385. When a single pipe is not sufficient to pass all the water, two or more pipes are placed side by side, with concrete well rammed between.

1464. Open Water Culverts.—These are generally of 2 feet span, with walls 2 feet thick, and of not greater depth than 3 feet. The foundation is of 12-inch paving placed as in foundations of box culverts. The walls, directly under the stringers, should be capped with large well-finished stones, so as to afford good bearings for the stringers, and properly distribute the loads of passing trains. Both stringers and cross-ties should be of sawed timber.

1465. Cattle Guards.—These are placed on each side of a public road crossing when the crossing takes place at grade. Formerly they were built like open culverts, with spans of from 3 to 5 feet and from 3 to 4 feet in depth. The abutment walls, upon which the wooden track stringers were laid, were from 2 to 2½ feet in thickness. The rails were laid directly upon the stringers, thus dispensing with cross-ties and leaving the space between the rails and abutments entirely open. Although possible for stock to get into these pits it was almost impossible for them to get out, and they often proved a cause of instead of a protection against accident.

The modern cattle guard dispenses with both masonry and excavation. It consists of two strips of 3-inch plank laid on cross-ties at a distance apart of 8 feet. Triangular strips of either wood or iron laid parallel to the rails are spiked to these pieces of plank, completely covering the space between the rails excepting space for the wheel flanges. A space 2 feet in width outside the rails is similarly covered, the whole closely resembling a gridiron, which is the name given to this form of cattle guard. It is quickly and cheaply made and thoroughly efficient.

1466. Open Passage Ways.—These are passage ways for public roads which cross the railroad below grade. The walls in part serve the purpose of retaining walls, and should have a thickness at their base of about $\frac{4}{10}$ of their height. The coping of the walls is arranged in the form of steps, as shown in the general plan of highway culvert; see Fig. 386. The height $A B$ of the embankment is 15 feet.

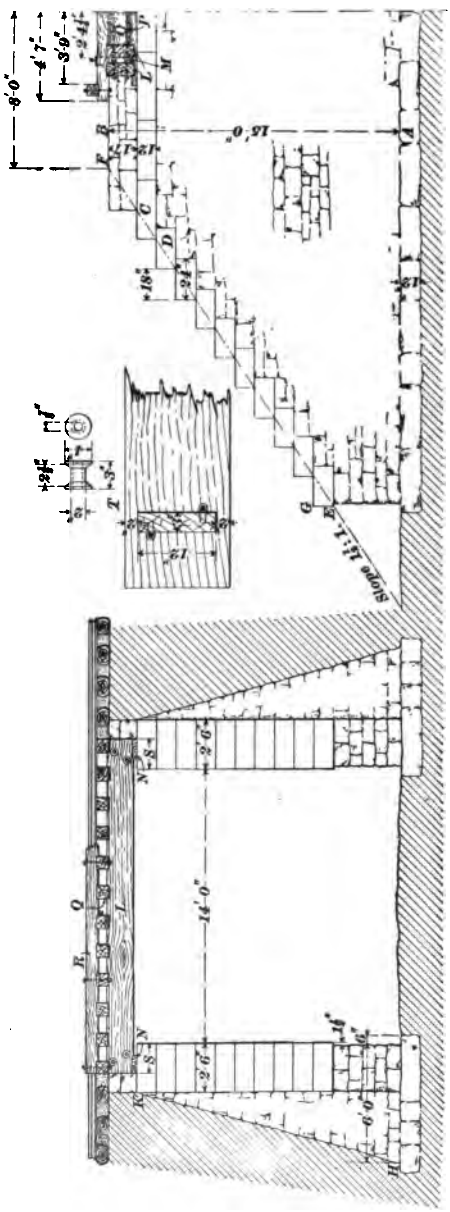


FIG. 886.

The steps $C\ D$, etc., are so arranged that the natural slope $E\ F$ of the embankment will just touch the back of the steps. The steps are not carried down to the level of the ground, but stop at G where the wall has a height between 4 and 5 feet. The section shows the thickness of the walls, which are $2\frac{1}{2}$ feet thick on the line of slope where the steps show. The thickness at the base is at all points about $\frac{4}{10}$ of the height of the embankment at that point, giving a thickness of about 6 feet where the embankment attains its full height, and finishing at the top with a thickness of $2\frac{1}{2}$ feet. The back of the wall is indicated by the line $H\ K$. The stringer L consists of two timbers 8 inches wide by 16 inches deep by 17 feet in length, separated by cast-iron

spools *M*, and called a **packed stringer.** The stringers rest on wooden bed-plates *N*, *N*, 12 inches wide by 3 inches thick, and are notched down 1 inch on the bed-plates. They are spaced 1 ft. 8 in. from the center line of the track, and are held in place by a strut *O*, 3 in. by 12 in. by 3 ft. 4 in. Stringer bolts *P* of $\frac{3}{4}$ in. round iron pass through both stringers, one on each side of the strut, and are fastened with nuts fitted with cast washers. The cross-ties *Q*, 8 in. wide by 7 in. deep, are spaced 18 in. between centers and notched down 1 in. on the stringers. The guard-rail *R* is 7 in. by 7 in. by 17 ft., and notched down 1 in. on the cross-ties and bolted to every fourth or fifth cross-tie with $\frac{1}{2}$ in. bolts. The bridge seat *S* for the stringers is 18 in. deep. The abutments behind the bridge seat are built up to the top of the embankment, thus keeping the earth from falling down upon the bridge seat. The spool *M* and a device for holding the strut *O* in position are shown in detail at *T*.

In ordinary open culvert masonry the bridge seat and steps are the only dressed stone used in the structure, the body of the walls being built of well-scabbled rubble. Large stones with good beds should compose the bulk of the walls, and when under-sized stones are used they must be thoroughly bonded by large ones. The wall plates should be placed as nearly over the center of the wall as possible, so that the shock and load of the passing train may be equally distributed throughout the abutments.

1467. Arched Culverts.—When the volume of water is too great to be discharged by a double-box culvert with openings 3 × 4 feet, an **arched culvert** is substituted with a single opening of the required area. In determining dimensions of culvert openings, the greater danger lies in making them too small. The volume of surface water discharged from a given area depends on widely differing conditions, and is often in apparent violation of all prescribed rules. It is not within the province of the engineer to attempt to meet phenomenal conditions, but he should meet common extremes, and there is no branch in railroad

construction where he so often blunders as in the matter of culverts.

1468. Parts of an Arch.—Fig. 387 represents an arched culvert in which the distance *D E* is called the **span,** *O F* the **rise,** the lower boundary line *D F E* the **soffit** or **intrados,** the upper boundary *G B H* the **back** or **extrados.** The end of the arch included between the lines

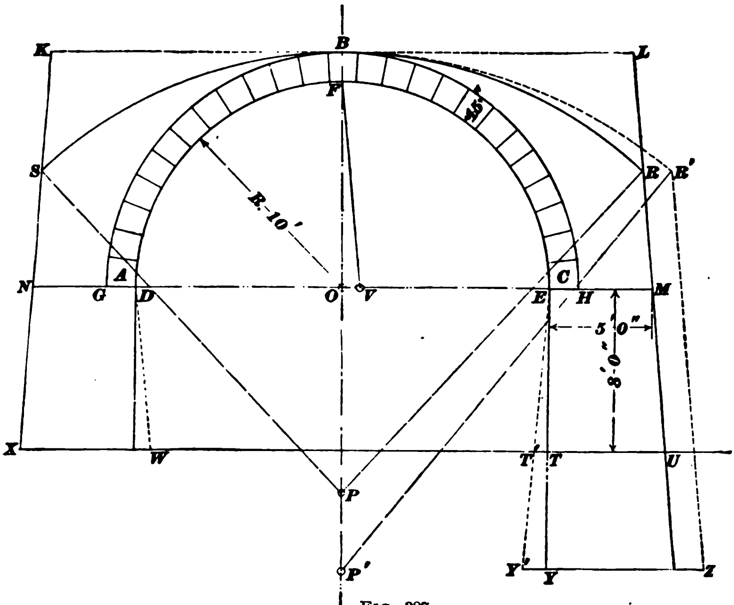


FIG. 387.

D F E and *G B H* is called the **face.** Lines level with *D* and *E* and at right angles to the face of the arch are called **springing lines** or **springs.** The blocks of which the arch is composed are called **arch stones** or **voussoirs.** The center one *B F* is the **keystone,** and the lowest ones *A* and *C* the **springers.** The parts *B G* and *B H* are the **haunches.** The spaces *B G N K* and *B H M L* are the **spandrels.** The material deposited in these spaces is the **spandrel filling.** It is sometimes earth and sometimes masonry or partly of both.

Arches according to their forms have different names.

That in Fig. 387 is a **semicircular arch,** and is the form commonly adopted in culvert building. A circular arch containing an arc of less than 180° is called a **segmental arch** (see Fig. 388). The arch shown in Fig. 389, composed

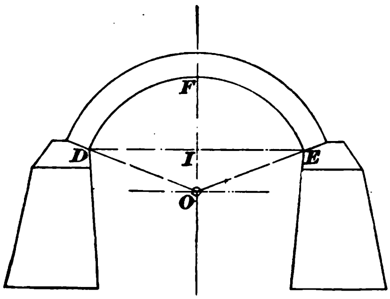


FIG. 388.

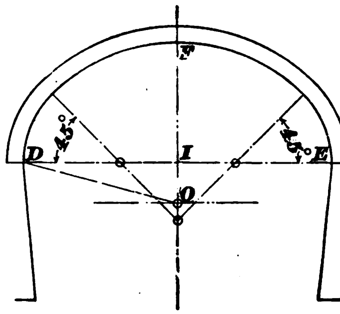


FIG. 389.

of three circular arcs, is called either an **elliptical** or a **three-centered arch.**

1469. To Find the Depth of Keystone.—For cut stone arches, whether circular or elliptic, find the radius $O\,D$, Figs. 387, 388, and 389, which will touch the arch at D, F, and E.

Rule I.—*Add together this radius and half the span D E. Take the square root of the sum. Divide this square root by 4 and add to the quotient* $\frac{2}{10}$ *of a foot.*

Or, by formula,

$$\textit{depth of keystone in feet} = \frac{\sqrt{\textit{radius} + \frac{1}{2}\,\textit{span}}}{4} + .2\,\textit{foot}. \qquad \textbf{(103.)}$$

For second-class work, increase this depth of keystone about $\frac{1}{8}$ part; *for brickwork or fair rubble*, about $\frac{1}{4}$ part.

EXAMPLE.—The radius $O\,D$ is 18 feet, the span $D\,E$ 36 feet; required, the depth of an arch of cut stone for second-class work and for brickwork.

SOLUTION.—Applying formula **103,** we have

For cut stone, depth of arch $= \frac{\sqrt{18 + 18}}{4} + .2$ foot $= 1.7$ feet. Ans.

For second-class work, increase depth of cut stone arch $\frac{1}{8} = 1.7 + \frac{1}{8} \times 1.7 = 1.91$ feet. Ans.

For brick or fair rubble, increase depth of cut stone arch $\frac{1}{4} = 1.7 + \frac{1}{4} \times 1.7 = 2.12$ feet. Ans.

Rankine's formula for depth of keystone in feet is,

$$\textit{depth of keystone in feet} = \sqrt{.12\ \textit{radius}}. \qquad \textbf{(104.)}$$

The latter formula may serve where all conditions are theoretically perfect, but, under ordinary conditions, the results given by this formula are too small. The arch stones of a 36-foot arch should be at least 1 ft. 9 in. in depth, for considerations of appearance as well as security.

To find the radius $O\ D$, Figs. 387, 388, and 389, whether the arch be circular, segmental, or elliptical:

Rule II.—*Square half the span; square the whole rise; add these squares together and divide the sum by twice the rise. The quotient is the required radius $O\ D$.*

EXAMPLE.—The span is 30 feet; the rise 10 feet; required, the radius $O\ D$.

SOLUTION.—Radius $= \dfrac{15^2 + 10^2}{20} = \dfrac{325}{20} = 16.25$ feet. Ans.

1470. To Proportion the Abutments for a Stone Arch, whether Circular or Elliptical:

Rule.—*Find the radius $O\ D$, Fig. 387, in feet which will touch the arch at D, F, and E. Divide this radius by 5. To the quotient, add $\frac{1}{10}$ of the rise and 2 feet. The sum will be the thickness $D\ N$ or $E\ M$ of each abutment at the springing line for any abutment whose height $E\ T$ does not exceed $1\frac{1}{2}$ times its base $T\ U$. If of rough rubble, add 6 inches to $E\ M$ to insure full thickness in every part.*

Or by formula,

$$\left.\begin{array}{l}\textit{Thickness of abut-}\\\textit{ment at spring line in}\\\textit{feet, when the height}\\\textit{does not exceed } 1\frac{1}{2}\\\textit{times the base}\end{array}\right\} = \frac{\textit{radius in feet}}{5} + \frac{\textit{rise in feet}}{10} + 2\,\textit{feet}. \qquad \textbf{(105.)}$$

Mark the points M and N thus obtained. Next, from the

center O of the span or chord $D E$, lay off $O V$ (Fig. 387) equal to $\frac{1}{24}$ of the span, and join F and V. Through the point M draw the line $R U$ parallel to $F V$, which will mark the back of the abutment $E T U M$. In the same way, draw the line $S N X$, marking the back of the other abutment. Now on the lines $M R$ and $N S$ mark the points R and S, their height above the line $M N$ being half $O B$, the full height of the arch. Produce the line $B O$, and upon that line as at P locate a center from which an arc may be described, passing through S, B, and R. This arc will mark the top of the masonry filling above the arch, except when the rise is about $\frac{1}{5}$ of the span or less, in which case the masonry backing must be carried up solid to the level $K L$ of the top of the arch. Ordinarily, the height $E T$ of the abutment will not exceed $1\frac{1}{2}$ times the base $T U$. In case the height should exceed $E T$, as $E Y$, make the base $Y Z$ equal to $T U$ increased by $\frac{1}{4}$ the additional height $T Y$. Then, from Z draw a line parallel to $U R$, which will mark the back line of the abutment. It is a common practice to give to the faces of the abutment a batter of from $\frac{1}{2}$ inch to 1 inch to the foot, shown in the dotted line $E T' Y'$. This considerably increases the base of the abutment, and, proportionately, its stability. An arc struck from the center P' with a radius $P' R'$, R' being level with R, will mark the top of the masonry filling above the arch.

1471. Foundations for Arch Culverts.—As arch culverts usually require a greater amount of masonry than box culverts, their foundation must be proportionally stronger. The general directions given for box culvert foundations will answer for arch culverts of small span, say from 4 to 8 feet. For greater spans, unless the natural foundation is firm and secure, such as hard clay, sand, gravel, or rock, a deep trench must be dug to receive the foundation. If the soil is soft or marshy, it may be necessary to drive piles and cut them off at a uniform elevation below the water-line, and fill between and to the depth of one foot above tops of piles with concrete made with hydraulic cement.

The trench should extend outside the lines of the foundation at least 12 inches, in order that the pressure of the superstructure may be sufficiently distributed. The first course of masonry should project at least 6 inches outside the main body of the abutment for the same reason, and should be composed of much larger stones than those which form the main body of the superstructure. The paving between the abutments and curbing at ends of arch should be of the same dimensions as adopted for box culverts. A partial section of arch culvert with concrete foundation is shown in Fig. 390. The stones forming the impost course

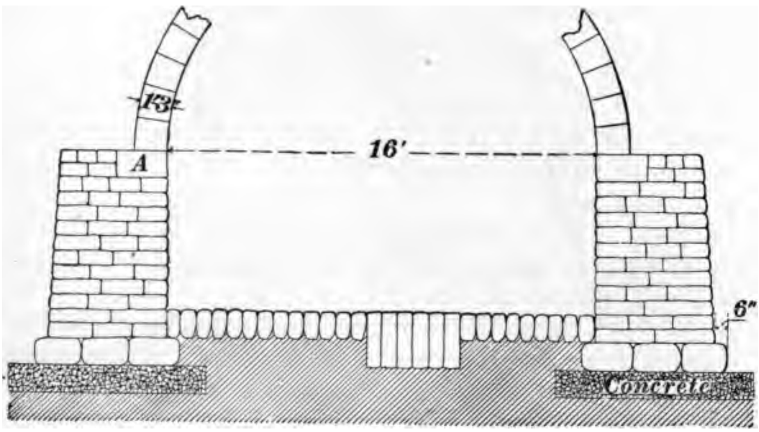


FIG. 390.

at *A*, in a culvert of 16 feet span, should be from 9 inches to 12 inches thick.

1472. Concrete.—The concrete for the foundations should be composed of the following ingredients: Cement, 1 part; sand, 3 parts; broken stone, 5 parts. If the concrete is to be deposited below the water level, **Portland** cement should invariably be used. If the pit is free from water at the time of construction, though ordinarily below water level, **Rosendale** or any other good American cement may be used. The value of concrete depends much upon the quality of the sand and broken stone used and the manner of mixing. Sand containing loam should never be used,

and if none other is available, the sand should be washed in a slight current of water, which will remove all the loam. The stone should be broken to a fairly uniform size, and contain no piece which will not pass through a $2\frac{1}{2}$-inch ring. If suitable stone is not available, hard-burned brickbats, broken to the requisite size, form an excellent substitute. For mixing concrete a level platform of rough boards is prepared, convenient to the foundation pit. A suitable quantity for mixing is the above given proportions in barrels of material, viz., 1 barrel of cement, 2 barrels of sand, and 5 barrels of broken stone. The broken stone is deposited in a regular pile, 12 inches in thickness. Upon the same platform the sand and cement are mixed in a dry state, after which water is added to them and they are worked into a mortar of uniform consistency. The mortar is then spread evenly over the stones, and the whole mixed with shovels, commencing at the outside of the pile and working towards the middle; which when reached, the shovelers reverse the movement, working towards the outside and casting the concrete towards the middle, so that when the outside of the pile is reached, the whole will be thoroughly mixed. It is injurious to work the concrete over *repeatedly*. Twice handling with the shovel, if thoroughly done, is sufficient. The concrete should be deposited in the foundation pit without delay, before setting commences; and with quick setting cements, especially in summer weather, the process is rapid. It is most conveniently handled in wheelbarrows, and can be deposited directly from them into the pit. In marshy situations, it is a common practice to confine the concrete by inclosures of rough boards held together by stakes driven in the ground. As soon as the concrete is deposited from the barrow, it must be spread with hoes or shovels into uniform layers, the thickness of which will depend upon the depth of concrete to be deposited. If only 12 inches of concrete, it should be deposited in two layers of 6 inches each, and each layer well rammed as soon as deposited.

Rammers of about 35 pounds weight, similar to those used in street paving, are recommended. They are of wood 4

feet long, 6 to 8 inches in diameter at foot, with a lifting handle. Ramming, when properly done, consolidates the mass of concrete about 5 or 6 per cent., rendering it less porous and increasing its strength. Water collecting upon the surface of the concrete gives evidence of sufficient ramming. The surface of the concrete should be brought to a uniform level, and sufficient time be allowed for setting before the abutments are started.

1473. Mortar.—Cement mortar should be exclusively used in the construction of arch culverts, the cement to be well tested and approved before being allowed to go into the work. Cement which does not show a tensile strength of 40 pounds to the square inch after remaining in water 24 hours should be rejected. The common American cements, if of good quality, mixed in the proportion of 1 part of cement to 2 parts of sand, will afford a mortar suitable for any ordinary engineering structure. Mortar should never be mixed in large quantities, lest its strength be impaired by setting before using. The proper practice is to mix only such quantities as can be used immediately, thus keeping the supply perfectly fresh and insuring the highest results. The cement and sand should always be mixed dry, the water being added afterwards, and the whole thoroughly worked with a hoe before using.

The use of cheap brands of cement is false economy. Ordinary cement will admit of sand in the proportion of *two* parts of sand to one of cement. The best Portland cement, especially for work not requiring rapid setting mortar, will bear *four* parts of sand. Hence, the latter may be used with the same economy as the former, even at twice the cost per barrel.

1474. Pointing of Joints.—Arch culverts for waterways are invariably rubble masonry, but of the best of its kind. Sometimes the corner stones of the abutments, as well as the arch stones of the faces, are of cut stone. The joints of these should be left open at the faces until the work is well advanced or completed, when they should be pointed

with mortar made of the best cement in the proportions of 1 part of cement to 1 part of sand, and neatly dressed with a pointing tool. The joints of the rubble masonry are simply *struck*, i. e., the trowel is pressed against the mortar and drawn the full length of the joint, forming a watershed for each joint. The joints are struck as the stones are laid, the same mortar being used at the faces as in the interior of the walls.

There are two principal methods used in pointing cut stone, as shown in Figs. 391 and 392. Fig. 391 shows the form in most general use. It is not so ornamental as that

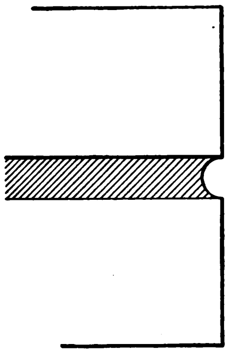


FIG. 391.

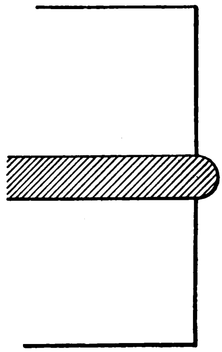


FIG. 392.

shown in Fig. 392, but it is less exposed to the weather, and, hence, is more enduring and a more certain protection to the joints. Mortar intended for pointing must be used immediately after mixing, and the pointing tool repeatedly run over the joint or bead, under considerable pressure, in order to compress the mortar and give it a smooth surface and uniform groove or projection.

1475. Centers for Arches.—A **center** is a temporary wooden structure for supporting an arch while it is being built. Centers are built lying flat on a fixed platform, to a full-sized drawing, and vary widely in design, according to the type and dimensions of the arch. The different parts of a center are given in Fig. 393, which is a standard type of centering for all arches of moderate span, say from 6 to 16 feet.

The frames A, A are made of ribs of 1½-inch plank and united as shown in the figure, breaking joints and fastened together with spikes. The ribs are fitted to the drawing as the frames are built. The ribs are 4 ft. 1 in. in length, 8 in. in width at ends, and 10 in. in width at middle, the edge being trimmed down to fit the curve of the arch. The chord B is composed of two planks, each 1½ in. thick by 10 in. in width and 16 ft. in length, spiked securely to the frames. The upright strut C is 3 in. thick by 10 in. in width, placed

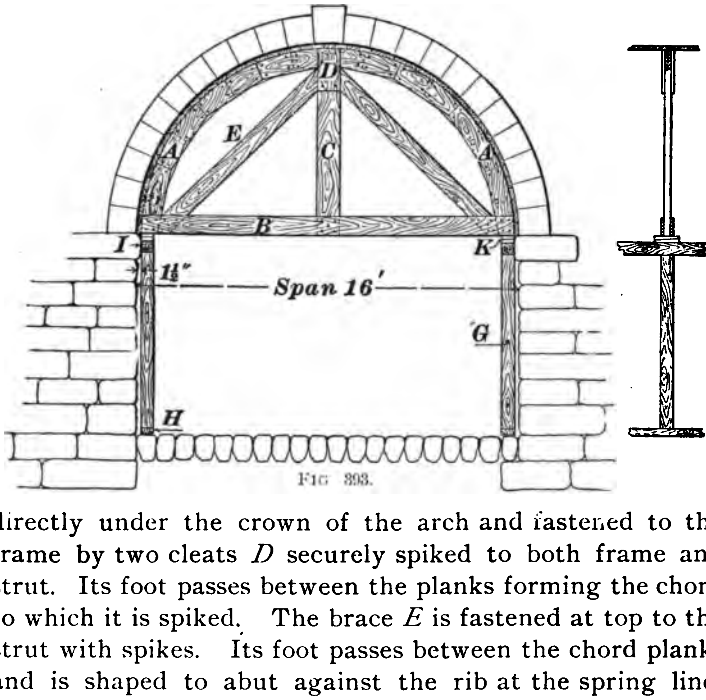


FIG. 393.

directly under the crown of the arch and fastened to the frame by two cleats D securely spiked to both frame and strut. Its foot passes between the planks forming the chord to which it is spiked. The brace E is fastened at top to the strut with spikes. Its foot passes between the chord planks and is shaped to abut against the rib at the spring line, being securely spiked to the chord. The frames are spaced 3 feet from center to center, and rest on 6 in. by 6 in. caps I which are supported by 6 in. by 6 in. posts G. These posts rest on 4 in. by 6 in. ground sills H which rest on the stone paving. On the caps directly under each frame are striking or lowering wedges K, by means of which the frames are raised in case any of the posts should settle.

1476. Striking Centers.—Upon the completion of the masonry, the lowering wedges are removed, which permits of the removal of the centering. This process is called *striking the centers.* There is great difference of opinion as to the length of time which should elapse after the completion of the masonry before the centers are struck. In the case of brick and rubble arches where the mortar forms a considerable part of the mass, a period of two or three months should elapse before the centers are struck. This will allow the mortar to harden and prevent undue compression of the joints and consequent settlement of the arch.

1477. General Directions for the Building of an Arch.—All arch stones must be laid with beds in radial lines. The joints at the intrados, or soffit, will, therefore, be thinner than at the extrados, or back. All rough projections must be removed from the beds of the stones, and the stones laid in firm beds with broken joints. Until the arch is half built, the backing need not be started, as an excess of weight on the haunches is liable to cause a lifting of the crown. In arches of large span it is a common practice to load the centering at the crown until 45° of the arch above the springing line is completed. When the 45° line is passed and the pressure on the centering becomes more nearly vertical, the backing must be carried up to take the pressure. The continuance of the centering will be no hindrance to traffic over the bridge.

1478. Wing Walls.—Wing walls are generally built with faces diverging at an angle of 120° from the face of the arch. Their foundations are prepared at the same time as the abutment foundations, and varied to suit the different heights of wall above them. Abutments and wing walls are carried up together, the stones of both walls interbonding so as to form one solid mass of masonry. The thickness of the wing walls at foundation line should ordinarily be $\frac{4}{10}$ of the full height of the wall at that point, with faces battered from 1 to $1\frac{1}{2}$ inches to the foot and having a thickness of $2\frac{1}{2}$ feet at the top.

This thickness of abutment is for first-class masonry. As our structure is of rubble, we add ½ foot to 4.4 feet, which gives 4.9 feet. We further increase the thickness of the abutments to 5.0 feet, which will insure perfect stability without any excess of masonry. We give to the back of the abutment wall a batter of 1 inch to the foot, making the thickness of the abutments at the ground line *X Y* 5 feet 6 inches. The height of the points *L* and *M* above the spring line is 4 feet and 9 inches, equal to one-half the full height *C E* of the arch. The arc *L E M* which limits the top of the backing or spandrel filling is struck with the radius *W L*, 18 feet 9 inches in length, found by trial. The wing walls *O* and *P* are shown in plan at *Q* and *R*. A section of wing wall at *S T* is shown in full at *U*. The top *N* of the parapet is 1 foot 9 inches above top of arch. The parapet and wing walls have a coping of dressed stone 6 in. in thickness.

1479. General Directions for Building Rubble Walls.—Small stones, excepting for back filling, should not be used, provided those of suitable size can be had at reasonable cost. Stones of too great size are equally objectionable unless they have full beds and reach from face to face of wall. Many rubble walls are built, as shown in Fig. 395, of large stones showing on one face, but extending only a short distance into the wall, while the back and body of the wall are composed of small stones. The back of the wall, having so much greater proportion of mortar than the front, will in high walls settle considerably more than the front, producing cracks in the masonry. The almost total lack of binders is an even greater source of weakness. Such a wall is objectionable in any situation, but when serving as a retaining wall for a

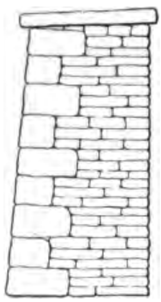


FIG. 395.

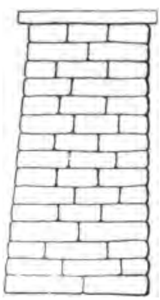


FIG. 396.

arch and give an equal number of arch stones on both sides of the key. If now we make the thickness of the arch stones 12 inches from center to center of joint on the soffit, the arch will contain 12 such stones on each side of the key and leave $13\frac{1}{2}$ inches for the thickness of the keystone. The height of the abutments FF' we take at 6 feet. The

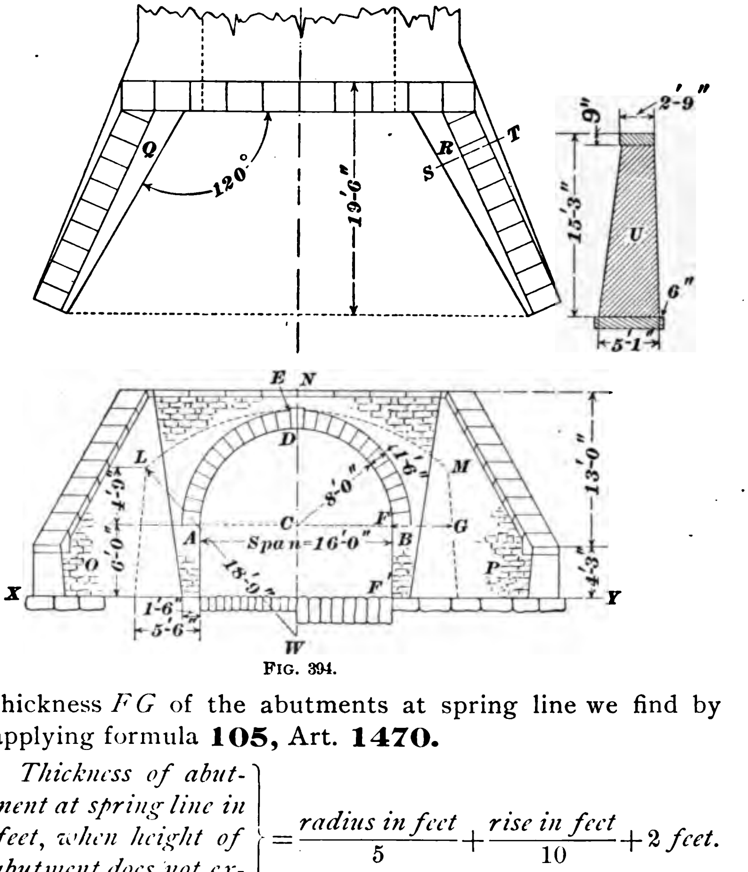


FIG. 394.

thickness FG of the abutments at spring line we find by applying formula **105,** Art. **1470.**

$$\left.\begin{array}{l}\textit{Thickness of abut-}\\ \textit{ment at spring line in}\\ \textit{feet, when height of}\\ \textit{abutment does not ex-}\\ \textit{ceed } 1\tfrac{1}{2} \textit{ times its base}\end{array}\right\} = \frac{\textit{radius in feet}}{5} + \frac{\textit{rise in feet}}{10} + 2\textit{ feet.}$$

Substituting given dimensions, we have thickness of abutment at spring line in feet $= \frac{8}{5} + \frac{8}{10} + 2$ ft. $= 4.4$ feet.

This thickness of abutment is for first-class masonry. As our structure is of rubble, we add ½ foot to 4.4 feet, which gives 4.9 feet. We further increase the thickness of the abutments to 5.0 feet, which will insure perfect stability without any excess of masonry. We give to the back of the abutment wall a batter of 1 inch to the foot, making the thickness of the abutments at the ground line *X Y* 5 feet 6 inches. The height of the points *L* and *M* above the spring line is 4 feet and 9 inches, equal to one-half the full height *C E* of the arch. The arc *L E M* which limits the top of the backing or spandrel filling is struck with the radius *W L*, 18 feet 9 inches in length, found by trial. The wing walls *O* and *P* are shown in plan at *Q* and *R*. A section of wing wall at *S T* is shown in full at *U*. The top *N* of the parapet is 1 foot 9 inches above top of arch. The parapet and wing walls have a coping of dressed stone 6 in. in thickness.

1479. General Directions for Building Rubble Walls.—Small stones, excepting for back filling, should not be used, provided those of suitable size can be had at reasonable cost. Stones of too great size are equally objectionable unless they have full beds and reach from face to face of wall. Many rubble walls are built, as shown in Fig. 395, of large stones showing on one face, but extending only a short distance into the wall, while the back and body of the wall are composed of small stones. The back of the wall, having so much greater proportion of mortar than the front, will in high walls settle considerably more than the front, producing cracks in the masonry. The almost total lack of binders is an even greater source of weakness. Such a wall is objectionable in any situation, but when serving as a retaining wall for a

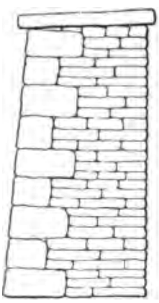


FIG. 395.

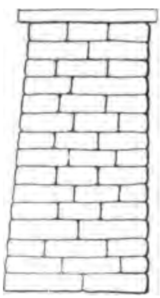


FIG. 396.

railroad embankment where the back filling is subjected to the constant vibrations caused by passing trains, its ultimate failure is almost certain.

A full proportion of large stones should show on both front and back and extend well into the wall, binding the wall compactly together, as shown in Fig. 396.

RETAINING WALLS.

1480. A **retaining wall** is one for sustaining the pressure of earth, sand, rock, or any other substance deposited behind it after it is built. The material deposited is called **filling** or **backing.** Retaining walls are much used in railroad construction, especially in sections where the natural slope of the ground approaches closely to that

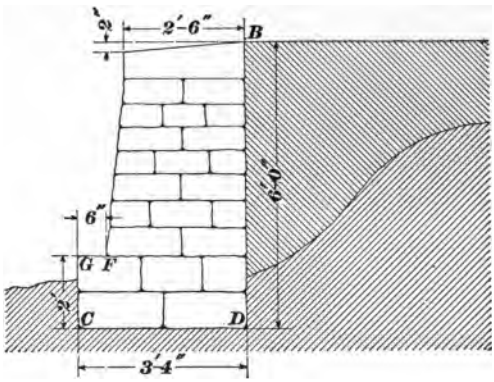


FIG. 397.

of the angle of ordinary earth filling, viz., $1\frac{1}{2}$ horizontal to 1 vertical. Railway tracks entering towns, especially where they cross or crowd other lines, terminal grounds, etc., invariably require retaining walls. The pressure exerted by the backing will vary greatly, depending upon the slope of the ground behind the wall, the nature of the material composing the backing, and the manner of depositing it; but chiefly depending upon the height of the backing. The usual form of retaining wall is shown in Fig. 397. There is

no invariable rule for determining the dimensions of retaining walls, and the rules of various authors differ widely. The following rule by Trautwine is based upon careful experiments and is widely adopted. The back of the wall is vertical, and the foundations not more than 3 ft. deep.

Rule.—*When the backing is deposited loosely, being dumped from carts, barrows, etc., wall of cut stone or first-class large ranged rubble in mortar, base C D equals .35 of the vertical height D B; wall of good common scabbled mortar rubble, or brick, base C D equals .4 of the vertical height D B; wall of well-scabbled dry rubble, base C D equals .5 of the vertical height D B.*

When the backing is deposited in layers and well rammed, these dimensions may be somewhat reduced, but there is no fixed rule. In general, the additional cost of spreading and ramming will quite equal the saving in masonry.

In Fig. 397, the height *B D* is 6 feet. The wall, supposed to be of dry rubble, has a base of 3 feet 4 inches. The foundation is laid in a trench about 1 foot in depth, with a footing or offset *F G* 6 inches in width. The face is battered 1 inch to the foot, which gives the wall a more substantial appearance, though clearly adding nothing to its stability.

Earth and sand are the materials commonly used for backing. When broken stone, gravel, boulders, or clay are to be used, additional weight must be given to the wall.

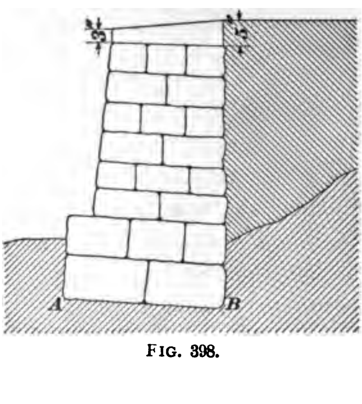


FIG. 398.

By inclining the base *A B* of the wall (see Fig. 398), the friction of the wall against the foundation is increased and the danger of overturning lessened. As was stated in Art. **1478,** the rough battered back of the wall also

increases the friction of the backing, tending to prevent overturning. The batter of the face should not exceed 1½ inches to the foot. Any increase is liable to catch water running down the face and carry it into the wall. This danger is increased where the joints of the masonry are inclined backwards, as in Fig. 398. To obviate this danger, the face stones are sometimes laid in mortar.

1481. Guarding Against Frost.—Where deep freezing occurs, the back of the wall should be sloped forwards, as shown in Fig. 399 at *a b*, and smoothly finished to lessen the hold of the frost, which might otherwise displace the masonry. The foot of the slope *b* should be at the *frost line*, usually three or four feet below the surface *a*.

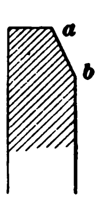


FIG. 399.

1482. Bulging.—Where walls are too thin, they usually first manifest their weakness by bulging outwards at about one-third of their height above the ground, as at *a*, Fig. 400. This effect is sometimes owing to the yielding of fresh mortar, and if not more than ¼ inch for each foot in thickness of wall at *a*, it need not cause apprehension.

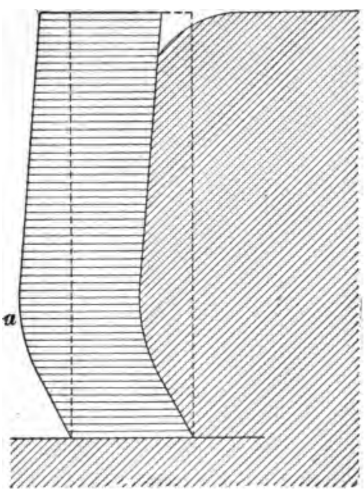


FIG. 400.

Sometimes retaining walls fail on account of the compression of the backing, causing settlement and increased pressure against the wall. This is especially frequent where the backing supports railway tracks carrying heavy and rapidly moving trains. In designing walls for such situations, this heavy additional weight must be provided for by additional weight in the wall.

1483. Offsetted Back.—Having proportioned a retaining wall *a b d c* in Fig. 401, by the foregoing rule, we can, by offsetting the back, as shown in the figure, considerably increase its stability without adding to the volume of the masonry.

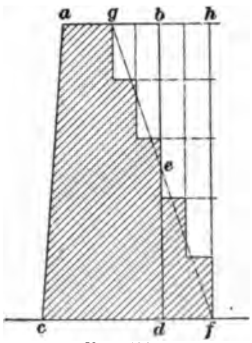


Fig. 401.

The offsets are determined as follows: Through *e*, the middle point of the back, draw any line *f g*. From *f* erect the perpendicular *f h*. Divide *g h* into any even number of parts, in this instance 4, and draw through these points of division lines parallel to *f h*. Then divide *f h* into 1 greater number of equal parts than *g h*, and through these points of division draw lines at right angles to *f h*, forming the offsets as shown in the figure. By increasing the thickness

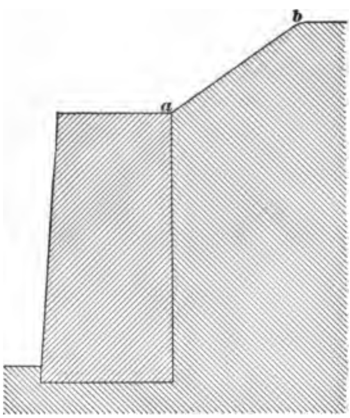


Fig. 402.

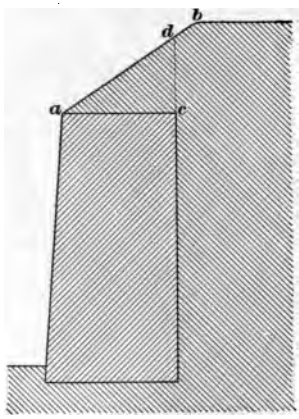


Fig. 403.

of the wall at the base, the center of gravity is lowered and the stability consequently increased. The backing included by the lines *g h* and *h f* exerts only vertical pressure against the offsets, which tends greatly to prevent the overturning of the wall.

1484. Surcharged Walls.—When the backing is higher than the top of the wall and slopes upwards from its inner edge *a*, at the natural slope *a b* of 1½ to 1 (see Fig. 402), the dimensions given in Art. **1480** will be inadequate for the increased pressure. The following table prepared by Trautwine gives dimensions of walls for all probable heights of backing:

TABLE 29.

Total Height of Backing as Compared with Height of Wall as 1.	Wall of Cut Stone in Mortar.	Good Mortar, Rubble, or Brick.	Wall of Good, Dry Rubble.	Total Height of Backing as Compared with Height of Wall as 1.	Wall of Cut Stone in Mortar.	Good Mortar, Rubble, or Brick.	Wall of Good, Dry Rubble.
	Thickness of Wall in Parts of Height.				Thickness of Wall in Parts of Height.		
1.0	.35	.40	.50	2.0	.58	.63	.73
1.1	.42	.47	.57	2.5	.60	.65	.75
1.2	.46	.51	.61	3.0	.62	.67	.77
1.3	.49	.54	.64	4.0	.63	.68	.78
1.4	.51	.56	.66	6.0	.64	.69	.79
1.5	.52	.57	.67	9.0	.65	.70	.80
1.6	.54	.59	.69	14.0	.66	.71	.81
1.7	.55	.60	.70	25.0			
1.8	.56	.61	.71	or more	.68	.73	.83

When the slope *a b* of the backing starts at the front *a* of the top of the wall (see Fig. 403), additional thickness is required. The triangle *a c d* showing section of earth above top of wall exerts only vertical pressure against the top of wall, and, hence, increases its stability. When the backing reaches above the top of the wall, as in Figs. 402 and 403, the wall is surcharged. The following table by Poncelet gives thickness of walls surcharged with dry sand from the outer edge *a*, Fig. 403:

TABLE 30.

Total Height of Backing as Compared with Height of Wall as 1.	Wall of Cut Stone in Mortar.	Wall of Brickwork.	Total Height of Backing as Compared with Height of Wall as 1.	Wall of Cut Stone in Mortar.	Wall of Brickwork.
	Thickness of Wall in Parts of Height.			Thickness of Wall in Parts of Height.	
1.0	.350	.452	2.0	.707	.930
1.1	.393	.498	2.4	.762	1.020
1.2	.439	.548	3.0	.811	1.110
1.3	.485	.604	4.0	.852	1.180
1.4	.533	.665	6.0	.883	1.250
1.5	.579	.726	11.0	.909	1.280
1.6	.617	.778	21.0	.922	1.310
1.7	.645	.824	31.0	.926	1.320
1.8	.668	.847	Infinite	.934	1.340
1.9	.690	.903			

The table is applied as follows: If the height of the backing is 20 feet and the retaining wall 10 feet, the tabular height of backing is given as 2, and the thickness of the retaining wall, if of cut stone, should be 10 × .707 = 7.07 feet.

1485. To Prevent Sliding.—*A retaining wall may slide from its foundation without losing its vertical position.* Where the wall is built on a timber platform or a smooth rock surface, the danger of sliding is great, owing to insufficient friction between the wall and foundation. To prevent this, strong projecting beams are built into a timber platform running at right angles to the direction in which the wall would slide, as shown in Fig. 404. On wet clay the friction is about $\frac{1}{3}$ the weight of the wall; on dry earth, from $\frac{1}{2}$ to $\frac{2}{3}$, and on sand or gravel, from $\frac{2}{3}$ to $\frac{3}{4}$ the weight of the wall.

The friction of masonry on a timber platform is about $\frac{6}{10}$ of its weight if dry and $\frac{3}{4}$ of its weight if wet, i. e., a retaining wall under the above given conditions will not slide under a pressure of $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, etc., of its total weight.

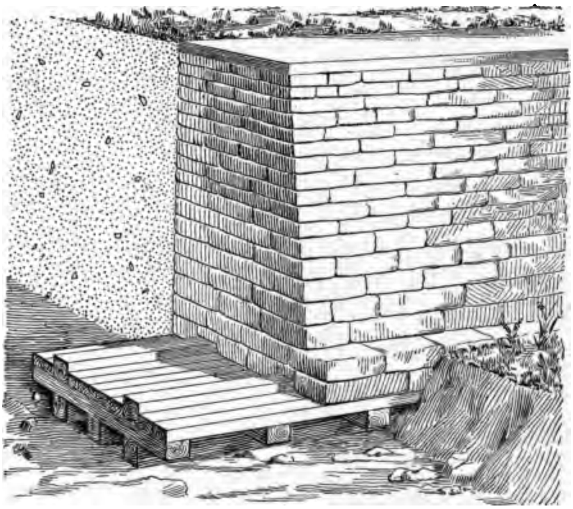


FIG. 404.

1486. On the Theory of Retaining Walls.—Let $a\ b\ d\ c$, Fig. 405, be a retaining wall with battered face and vertical back. The top $b\ e$ of the backing is level with the top of the wall. Let $d\ e$ represent the natural slope of the material composing the filling, viz., $1\frac{1}{2}$ horizontal to 1 vertical, which is the average of materials used for back filling.

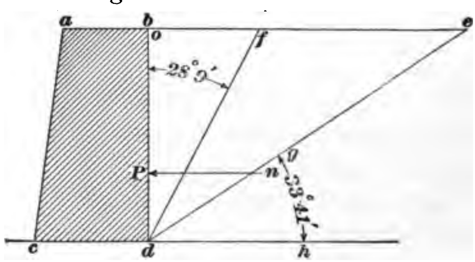


FIG. 405.

It is assumed that the wall $a\ b\ d\ c$ is heavy enough to resist sliding along its base, and that it can fail only by overturning, i. e., rotating about its toe c. Now, if the angle

o d c between the vertical line *o d* drawn from the inner bottom edge of the wall and the natural slope *d c* be divided by the line *d f* into two equal angles *o d f* and *f d e*, the *angle o d f* is called the *angle* and the *line d f* the *slope of maximum pressure.* The triangular prism of earth *o d f* is called *the prism of maximum pressure* because, if considered as a wedge acting against the back of the wall, it would exert a greater pressure against it than would the entire triangle *o d c* of earth considered as a single wedge. For though the last is more than double the weight of the former, yet it receives much greater support from the underlying earth. It has been proved by experiment that if the triangle of earth *o d c* be divided by any line *d f* into wedges, the wedge that will press most against the wall is that formed when the line *d f* divides the angle *o d e* into two equal parts.

The angle *o d h* formed by the vertical *o d* and the horizontal *d h* is 90°. The angle of natural slope *h d e* is 33° 41′; hence, the angle *o d f* of maximum pressure is equal to $90° - 33° 41' \div 2 = 28° 09'$.

In making calculations, only *one foot* of the length of *wall* and of the *backing* is taken, so that all that is necessary is to take the area of the section of the wall and backing. The material composing the backing is supposed to be perfectly dry and possessing no cohesive power, which is practically true of pure sand.

If we conceive the wall *a b d c*, Fig. 405, to be suddenly removed, the triangle *b d f* of sand included between the line of maximum pressure *d f* and the vertical back *b d* of the wall would slide downwards impelled by a force *n P*, acting in a direction *n P* at right angles to the side *b d* of the triangle, i. e., at right angles to the vertical back *b d* of the wall, *its center of force* being at *P* distant $\frac{1}{3}$ way between *b* and *d*, measured from the bottom of the wall *d*. The amount of this force is expressed by the following formula:

$$\begin{matrix}\textit{Perpendicular}\\ \textit{pressure } n\,P\end{matrix} = \frac{\textit{weight of triangle of earth } bdf \times of}{\textit{vertical depth } o\,d}. \qquad \textbf{(106.)}$$

This formula not only applies to walls with vertical backs,

as in Fig. 405, but to those with inclined backs, as in Fig. 406, for inclinations as high as 6 inches horizontal to 1 foot vertical, which is rarely met with and never exceeded.

1487. Friction Caused by Pressure of Backing.—If all the backing material contained between the line of natural slope and the back of the wall were unconfined, it would slide, producing *motion*, but confined by the retaining wall, the force is converted into *pressure* of earth against the back of the wall, resisted by the *friction* between the compressed earth and the wall.

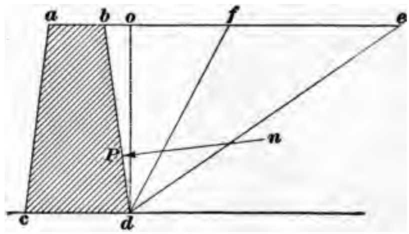


FIG. 406.

If the wall were to begin to overturn about its toe c (Figs. 405 and 406) as a fulcrum, its back $b\ d$ would rise, producing friction against the backing. So long as the wall does not move, the friction of the backing acts constantly, and must, therefore, be one of the forces which *prevent* overturning. We ascertain the amount and effect of this friction as follows: Let $a\ b\ d\ c$, Fig. 407, be a retaining wall, and let $n\ P$ represent to some *scale* the perpendicular pressure against the back of the wall calculated by formula **106,**

$$\frac{\textit{perpendicular}}{\textit{pressure } n\,P} = \frac{\textit{weight of triangle } b\,d\,f \times o\,f}{\textit{vertical depth } o\,d}.$$

Make the angle $n\ P\ h$ equal to the angle of wall friction, viz., that at which a plane of masonry must be inclined in order that dry sand and earth may slide freely over it, and taken at 33° 41′ with the horizontal. Draw $n\ h$ perpendicular to $n\ P$ and complete the parallelogram $n\ h\ k\ P$. Then, $k\ P$ will represent to the same scale the *amount of friction against the back* of the wall. As the friction acts in the direction of the back $b\ d$ of the wall, it may be considered as acting at any point P of the line of the back, and we will have two forces, viz., the perpendicular pressure $n\ P$ and the friction

k P acting at *P*. By composition and resolution of forces, the diagonal *h P* measured to the same scale will give us the amount of their resultant, which is approximately the *single theoretical force* both in *amount* and *direction* which the wall has to resist. This force includes the wall friction. The force *h P* is always equal to the perpendicular force *n P* divided by the cosine of the angle of wall friction. The cosine of the angle of wall friction is .832, and the value of the force *h P* may be expressed in the following formula:

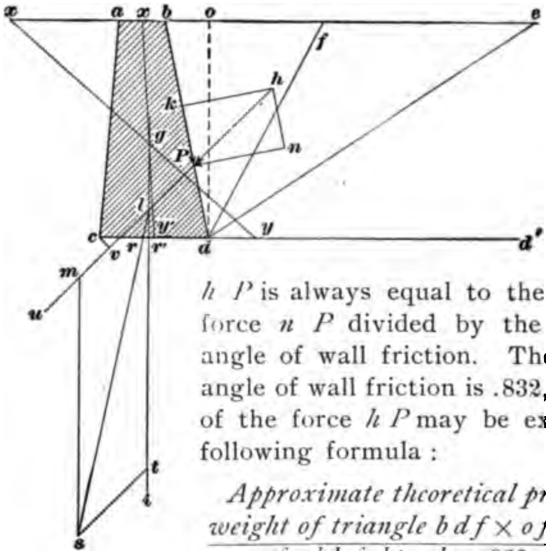


FIG. 407.

$$\textit{Approximate theoretical pressure } h\,P = \frac{\textit{weight of triangle } b\,d\,f \times o\,f}{\textit{vertical height } o\,d \times .832}. \qquad \textbf{(107.)}$$

When the back of the wall does not incline forwards more than 6 inches horizontal to 1 foot vertical, equal to an angle of about 26° 34′, the following formula by Trautwine is used, viz.:

$$\textit{Approximate theoretical pressure } h\,P = \textit{weight of triangle } b\,d\,f \times .643, \qquad \textbf{(108.)}$$

which includes friction of earth against the back of the wall. When the back of the wall is offsetted, as in Fig. 401, the direction of the pressure of the earth will be the same as though the wall had the batter *f g*.

1488. To Find the Overturning and Resisting Forces.—*To find the overturning tendency of the earth pressure and the resistance of the wall against being overturned about its toe c, as a fulcrum*, see Fig. 407. Find the center of gravity *g* of the wall, and through *g* draw the vertical

line $g\ i$. Produce the line of pressure $h\ P$, and draw $c\ v$ at right angles to this line. To any convenient scale, lay off $l\ t$ equal to the weight of the wall and to the same scale $l\ m$ equal to the pressure $h\ P$. Complete the parallelogram $l\ m\ s\ t$. The diagonal $l\ s$ will be the resultant of the pressure and the weight of the wall. The stability of the wall will be the greater as the distance $c\ r$, from the toe to the point where the resultant $l\ s$ cuts the base, increases. To insure stability, $c\ r$ must be greater than $\frac{1}{6}\ c\ d$.

The pressure $h\ P$, if multiplied by its leverage $c\ v$, will give the moment of the pressure about c, and the weight of the wall $l\ t$ multiplied by its leverage $c\ r'$ will give the moment of the wall. The wall is secure against overturning in proportion as its moment exceeds that of the pressure.

For example, let the height of the wall $a\ b\ d\ c$, in Fig. 407, be 9 ft.; the thickness at the base $c\ d$, 4.5 ft., and at the top $a\ b$, 2 ft., and the batter of $a\ c$ be 1 in. to the ft. The triangle of earth $b\ d\ f$ has a base $b\ f = 6.57$ ft. and altitude $d\ o = 9$ ft. Taking the section as 1 foot in thickness, Art. **1486,** we have the contents equal to $6.57 \times 9 \div 2 = 29.56$ cu. ft. Assuming the material to weigh 120 lb. per cu. ft., the weight of the triangle $b\ d\ f$ is $29.56 \times 120 = 3{,}547$ lb., $o\ f = 4.81$ ft. $3{,}547 \times 4.81 = 17{,}061$. $17{,}061 \div o\ d = 1{,}895.7$ lb. = the perpendicular pressure $n\ P$. Lay off on a line perpendicular to the back of the wall at P, to a scale of 2,000 lb. = 1 in., $n\ P = 1{,}895.7 \div 2{,}000 = .948$ in., the perpendicular pressure. Draw $P\ h$, making the angle $n\ P\ h = 33°\ 41'$. Draw $n\ h$ intersecting $h\ P$ in h; then will $n\ h$ to the same scale equal the friction of the earth against the back of the wall. Completing this parallelogram, $n\ h\ k\ P$, the diagonal $h\ P = 1.139$ in., which, to a scale of 2,000 lb. to the inch, amounts to 2,278 lb., and is the resultant of the pressure and the friction.

Produce the resultant $h\ P$ to u. We next find the center of gravity g of the wall $a\ b\ d\ c$. The section of the wall is a trapezoid, and the center of gravity g is readily found as follows: Produce the upper base of the section to x, making $a\ x = c\ d = 4.5$ feet. Produce the lower base in the opposite

direction to y, making $d\,y = a\,b = 2$ ft. Join x and y. Find the middle points x' and y' of the upper and lower bases of the section. Join these points. The intersection g of the lines $x\ y$ and $x'\ y'$ is the center of gravity of the trapezoid $a\ b\ d\ c$.

The volume of the section of wall $a\ b\ d\ c$ is readily found. The sum of top and bottom widths $= 2.0 + 4.5 = 6.5$ ft. $6.5 \div 2 = 3.25$ ft. $3.25 \times 9 = 29.25$ cu. ft. $29.25 \times 154 =$ 4,504 lb. (the weight per cubic foot of good mortar rubble

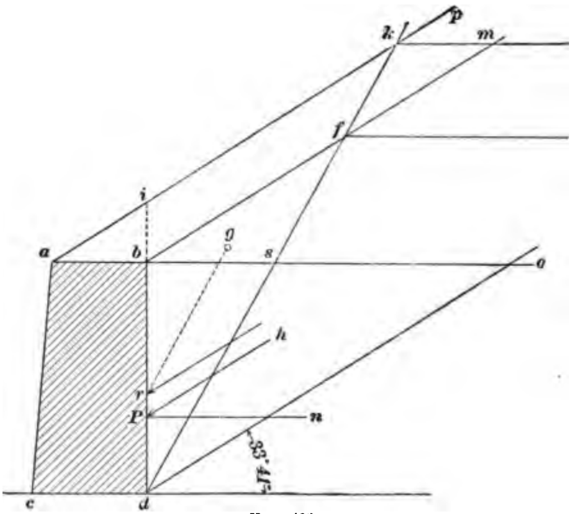


FIG. 408.

$= 154$ lb.) $=$ the weight of the section $a\ b\ d\ c$. Draw through g a vertical line $g\ i$, and lay off in it to a scale of 2,000 lb. to the inch from the point l, where the line of gravity intersects the prolongation of the line of pressure $h\ P$, the length $l\ t$ equal to 4,504 lb., the weight of the wall. Lay off from l on the prolongation of $h\ P$, $l\ m$ equal to 2,278 lb. to the same scale. Complete the parallelogram $l\ m\ s\ t$. The diagonal $l\ s$ represents the resultant of the pressure and of the weight of the wall. The distance $c\ r$ from the toe c to the intersection of the resultant $l\ s$ with the base $c\ d$ is more than $\frac{1}{3}$ of the width of the base, which insures ample stability.

1489. Pressure of the Backing on Surcharged Walls.—In Fig. 408, the surcharge of backing *m b o* slopes from *b* at its natural slope and attains its maximum pressure where the slope of maximum pressure *d k* intersects the natural slope *b m* at *f*. Any additional height of surcharge does not increase this pressure. If the surcharge slopes from *a*, as shown by the line *a p*, or from any point between *a* and *b*, then the slope of maximum pressure must be extended intersecting the slope from *a* in the point *k*. The prism of maximum pressure will then be *d i k*. The triangle of earth *a b i* on the top of the wall exerts no pressure against the back of the wall, but adds to its stability.

Having found the weight of the triangle *b d f*, we have, by formula **108**, Art. **1487**,

$$\textit{approximate pressure} = \text{weight of triangle } b\,d\,f \times .643,$$

which includes the pressure of the backing and the friction of the earth against the back of the wall.

Draw $P\,n$ perpendicular to the back of the wall and draw $h\,P$, making the angle $n\,P\,h = 33°\ 41'$, the angle of wall friction. Then, $h\,P$ will be the direction of the pressure. The point of application of this pressure will not always be at P, $\frac{1}{3}$ of the height of *b d* measured from *d*, but above *P*, as at *r*, where a line drawn from the center of gravity *g* of the *prism of maximum pressure d i k* (omitting any earth resting directly upon the top of the wall) and parallel to the line *d k* of maximum pressure cuts the back *b d* of the wall. The center of pressure *P* will be at $\frac{1}{3}$ the height of the wall when the sustained earth *d b s* or *d b f* forms a *complete triangle*, one of whose angles is at *b*, the *inner top edge* of the wall. For all other surcharges, the point of pressure will be *above P*.

1490. General Directions and Precautions.—The batter of the face of the wall should not (unless circumstances require it) be greater than $1\frac{1}{2}$ inches to the foot. When the batter is greater, the joints catch more or less of the water running down the face, which is carried into the joints, tending to weaken the mortar. All mortar used in

retaining walls should have some admixture of **cement**, especially in the lower courses of masonry. Common lime mortar will not set so long as it is kept wet by the moisture which comes from the foundation and the moist earth backing. If allowed to remain long in this condition, it becomes worthless. When the batter is considerably greater than 1½ inches to the foot, the water may be excluded from the joints by careful pointing.

EXCAVATION.

1491. Earth Work.—Earth work embraces the excavation of all earthy material included within the section of the roadway above the grade line and the transporting and depositing of it upon those sections of the roadway below the grade line, forming the embankment. It also includes all excavations for foundations above the water-line, the cutting of ditches, changing of watercourses, and all excavation ordinarily required in the formation and protection of the roadway. Those parts of the roadway formed by excavation are called **cuts** and, according to their various sections, are called **through cuts,** those in which the entire width of the roadway is in excavation, and **side cuts,** in which only a part of the roadway is in excavation and a part in embankment.

Ordinarily the side slopes in excavation are made at an

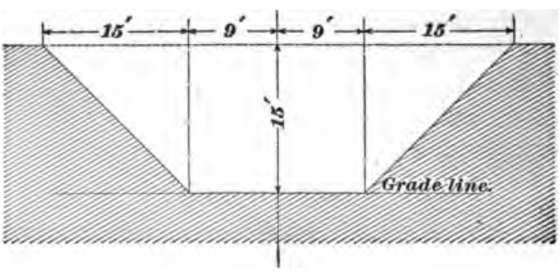


FIG. 409.

inclination of 1 horizontal to 1 vertical, and the side slopes of embankments at an inclination of 1½ horizontal to 1 vertical. The slopes for cuts in the alluvial soils of our western

prairies are commonly made 1½ horizontal to 1 vertical, on account of their small resistance to frost and water. Fig. 409 represents a section of a through cut, Fig. 410 a com-

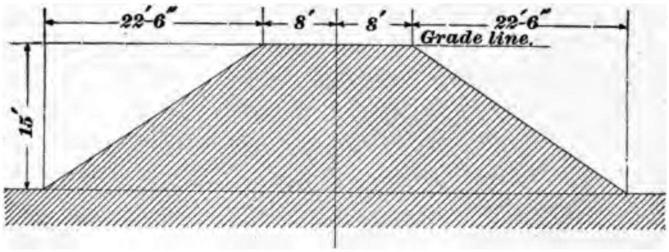


FIG. 410.

plete section of embankment, and Fig. 411 a side cut, in which part is excavation and part embankment.

Methods in handling earth vary widely, depending upon the character of material, the situation, the magnitude of

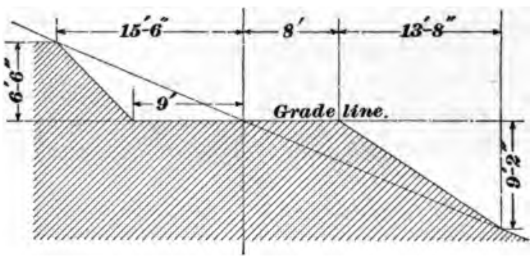


FIG. 411.

the work, and very greatly upon the contractor. The section of roadway shown in Fig. 411 admits of very economical construction. The material is loosened with the plow or pick, and cast by hand directly from the cut to the adjacent embankment.

1492. The Use of a Road Machine.—A more expeditious and economical practice is to handle the material with a road machine. A road machine of great strength, especially designed for railroad use, is much used for work of this character. The blade of the machine cuts and scrapes the material from the higher points and carries it

along, depositing it in the low places. An experienced foreman, with a good and well-manned machine, can almost complete the work on a side hill line, leaving only a little trimming and ditching to be done by hand. Before using the road machine, the ground is broken with a plow. Earth under favorable conditions can be handled by road machines at from 10 to 12 cents per cubic yard. A plow especially designed for loosening earthy material is called a "railroad plow." It is amply strong enough to stand the draft of

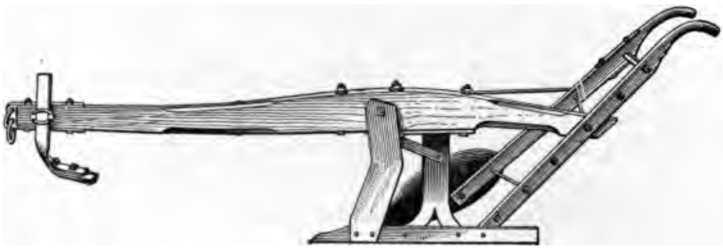


FIG. 412.

three heavy teams, and is an important part of a grading outfit. Fig. 412 shows a good form of a railroad plow.

1493. Wheelbarrow Work.—The transportation of earth by wheelbarrows has of late years been practically abandoned by the more progressive contractors. There are, however, situations where they may be used to advantage. When the haul is short and the work difficult of access to teams, the pick, shovel, and wheelbarrow, on account of their portability, are brought into use.

It frequently happens, especially after protracted rains, that teams can not be used on account of miring. Under such conditions, the work can be carried on with wheelbarrows. A runway of planks under all circumstances is necessary to secure a firm and even tread for the wheels.

In wheelbarrow work, each man loads his own wheelbarrow. A sufficient number of pickers must be employed to keep a constant supply of loosened material. The gangway planks must be kept smooth, in order that there may be no impediment to wheeling. A wheelbarrow carries $\frac{1}{14}$ of a cubic yard of ordinary material. The men in wheeling move

at the rate of about 200 feet per minute, or $2\frac{1}{2}$ miles per hour, which is equivalent to 100 feet each way per minute, technically called 100 feet of **lead.** The length of time required in making a round trip from the *pit* (as the place of excavation is called) to the dump will be as many minutes as there are 100 feet of lead; to which must be added $1\frac{1}{4}$ minutes for loading and dumping. Delays of various kinds are met with, which will consume about $\frac{1}{10}$ of the time; so that in calculating the number of trips which each man will make in a day, the total number of minutes in a working day of 10 hours, viz., 600 minutes, must be reduced by 60 minutes, leaving 540 minutes for actual work. We will, therefore, have

$$\text{the number of trips for each man per day} = \frac{540}{1.25 + \text{the number of 100 feet lengths of lead}}.$$

EXAMPLE.—Allowing \$1.20 per day as wages for men, what will be the cost to the contractor for handling earth with wheelbarrows, the lead being 500 feet and the gang consisting of 30 laborers?

SOLUTION.—The number of trips per day $= \frac{540}{1.25 + 5} = 86.4$ trips.

As 14 trips are required for each cubic yard of material, the number of cubic yards handled per day per man $= \frac{86.4}{14} = 6.17$ cubic yards, and the cost per cubic yard to the contractor for loading and wheeling will be $\frac{\$1.20}{6.17} = 19.45$ cents per cubic yard.

It will require one picker for each 5 wheelbarrows. Five wheelbarrows will handle $6.17 \times 5 = 30.85$ cubic yards. Consequently, we must add to the above cost per cubic yard \$1.20, the wages of the picker, divided by 30.85, the number of yards loosened, $\frac{1.20}{30.85} = 3.89$ cents.

In addition to the above items, there must be added the wages of a foreman and water carrier, one each for a gang of 30 men, of which 25 handle wheelbarrows. A foreman will cost \$2.50 per day and water carrier \$1.00 per day, making \$3.50 per day. The additional charge against each wheelbarrow will, therefore, be $\frac{\$3.50}{25} = 14.00$ cents, and this sum divided by the number of cubic yards carried by each wheelbarrow will give amount to be added to each cubic yard for superintendence and water carrier, or $\frac{14.00 \text{ cents}}{6.17} = 2.27$ cents per cubic yard.

Placing the various items of cost in order, we have

Cost of wheeling	19.45 cents per cu. yd.
Cost of picking	3.89 cents per cu. yd.
Cost of foreman and water carrier	2.27 cents per cu. yd.
Wear of tools and wheelbarrows	.50 cent per cu. yd.
Total cost to contractor	26.11 cents per cu. yd.
Add 15 per cent. for contractor's profit	3.92 cents per cu. yd.
Cost to R. R. Company	30.03 cents per cu. yd.

A contractor can not undertake wheelbarrow work under 30 cents per cubic yard, which is much in excess of prices paid for earth excavation for railroad work in 1894–5. If, however, the contractor is enabled through the use of the wheelbarrow to do work which would be difficult to accomplish without it, its value is at once manifest, and losses which he may suffer on sections requiring wheelbarrow work he can readily make good on sections admitting of more modern methods.

1494. Cart Work.—The cost of loading, hauling, and dumping material by carts may be calculated in the same way as in calculating cost by wheelbarrows. An ordinary earth cart weighs about $\frac{1}{2}$ ton and will carry on an average $\frac{1}{3}$ cubic yard of the various soils encountered in railroad construction, measured in place before being loosened. The material to be excavated is loosened in two ways, viz., by pick and by plow. When picks are used, the cut is taken out complete to grade, commencing where the grade line cuts the surface of the ground and working backwards, the material being hauled and dumped to form the adjacent embankment. The carts are backed up to the breast of the cut (as it is called), and the material loaded with shovels. A shoveler can shovel $\frac{1}{3}$ cubic yard of sandy soil into a cart in about 5 minutes; of loam, in 6 minutes, and of heavy clayey soil, in 7 minutes. By working constantly without any delays, he could shovel in a day of 10 hours, or 600 minutes, of light sandy soil, 120 loads; of loam, 100 loads, and of heavy soil, 86 loads. He will, however, lose about $\frac{3}{10}$ of his time through delays in waiting for carts and from other causes. The cost of loading carts is determined as follows: 600, the

whole number of minutes in a working day, less 180 minutes lost through delays, leave 420 minutes actually employed in work; and $\frac{420}{5} = 84$, the number of cart loads of light sandy soil which will be a day's work for one shoveler; $\frac{420}{6} = 70$, the number of loads of loam, and $\frac{420}{7} = 60$, the number of loads of heavy soil. The cost of shoveling into carts, with wages at $1.20 per day, will be, respectively, $\frac{1.20}{84} = 1.43$ cents per load for sandy soil; $\frac{1.20}{70} = 1.71$ cents per load for loam, and $\frac{1.20}{60} = 2$ cents per load for heavy soil. As it requires 3 loads to make one yard, the cost for shoveling per cubic yard will be $1.43 \times 3 = 4.29$ cents per cubic yard for sandy soil; $1.71 \times 3 = 5.13$ cents per cubic yard for loam, and $2 \times 3 = 6$ cents per cubic yard for heavy soil. The cost of picking will, of course, be the same as that given in Art. **1493** for the wheelbarrow work, viz., 3.89 cents per cubic yard. A horse will haul a cart at the rate of about 2½ miles per hour, equivalent to 200 feet per minute, or 100 feet going and coming per minute, i. e., 1 minute for each 100 feet of lead. Besides the time consumed in going and coming to and from the dump, there is a loss of about 4 minutes to each trip, which time is consumed in loading, turning, and dumping. The number of trips per day for each cart will, therefore, be the number of minutes in a working day divided by 4 plus the number of 100 feet lengths of lead. For example, suppose the lead is 800 feet, we will then have

$$\text{number of cart trips per day} = \frac{600}{4 + 8} = 50 \text{ trips.}$$

As 1 cubic yard of material in place, i. e., before being loosened, will make 3 cart loads, the number of cubic yards transported by each cart per day will be the number of cart loads handled divided by 3. Accordingly, we have $\frac{50}{3} =$

16.66 cubic yards, a day's work for each cart. With labor at \$1.20 per day, the expense of a horse will be about \$1.00, the use of cart and harness 25 cents, and as 1 driver at \$1.00 per day can attend to 4 carts, the total charge against each cart will be

Horse	\$1.00
Cart and harness	.25
Driver	.25
Total	\$1.50

The cost of hauling per cubic yard will, therefore, be the cost of cart divided by the number of cubic yards hauled, and we have $\frac{\$1.50}{16.66} = 9$ cents per cubic yard.

A man is constantly employed on the dump to assist in dumping the carts and spreading material in layers, which will cost an average of 1 cent per cubic yard. A gang of 10 carts will require 1 foreman at \$2.50 per day and water carrier at \$1.00 per day. The cost per cubic yard for superintendence and water carrier will, therefore, be \$3.50 divided by the total number of cubic yards hauled by 10 carts. Each cart hauls 16.66 cubic yards, and 10 carts will haul 16.66 $\times 10 = 166.6$ cubic yards and $\frac{\$3.50}{166.6} = 2.1$ cents per cubic yard.

In hauling loam, the amount of the foregoing items of cost per cubic yard will be:

Loosening	3.89	cents per cubic yard.
Shoveling	5.13	cents per cubic yard.
Hauling	9.00	cents per cubic yard.
Dumping and spreading	1.00	cent per cubic yard.
Superintendence	2.10	cents per cubic yard.
Add for sharpening and use of tools	.50	cent per cubic yard.
Total cost to contractor	21.62	cents per cubic yard.
Add 15 per cent. for contractor's profit	3.24	
Cost to R. R. Company	24.86	cents per cubic yard.

The items given are supposed to include repairs of cart roads (a very important matter) and the trimming and ditching of cuts. The cart, like the wheelbarrow, is becoming obsolete in modern railroad construction. Its place is being taken by road machines, wheeled scrapers, dump cars, and steam excavators. The pick and shovel are still largely used, especially on the western plains. Hundreds of miles of road are built on the level prairies by **casting,** that is, by shoveling the material directly from borrow pits at the side of the roadway into the embankment. The soil is generally soft enough to move without the use of a pick, and often for miles the expense of hauling is entirely saved. Under such conditions earth may be handled at from 14 to 16 cents per cubic yard at fair profit. The embankment on such sections has an average height of about 2 feet. Not an economic investment for the bondholders of the road, but it is often very profitable for those who sell the bonds.

1495. Wheeled Scraper Work.—The body of the **wheeled scraper** (see Fig. 413) is of sheet steel about 3½

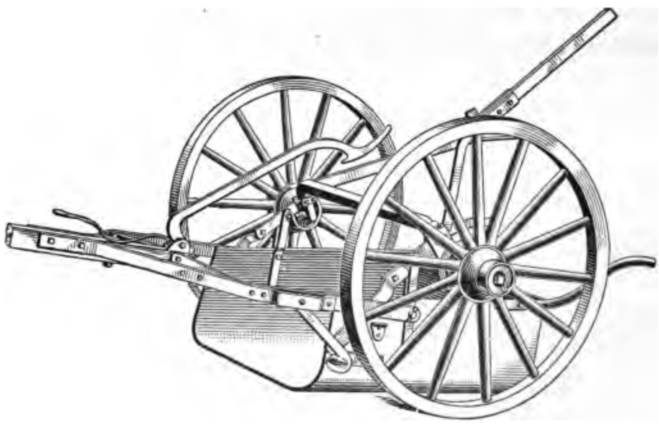


FIG. 413.

feet square and 15 inches deep, containing about ½ cubic yard when level full. The box is open in front, and can be raised or lowered and revolves on a horizontal axis. All

movements of the box are made by means of levers. In loading, the box is lowered so that the cutting edge of the open front cuts into the ground. A strong team, and usually a second team called a *snatch team*, haul the scraper, which fills itself in the same way as an ordinary hand shovel is filled. When full, the box is raised about 1 foot from the ground by means of a lever, and the snatch team is detached. The loaded scraper is then hauled to the dump, the dumping being effected by means of a lever, without stopping the team, which is constantly moving. The wheels have broad tires, which prevent their cutting into the ground. Where wheeled scrapers are used, the material is always loosened with a plow. The cut is not worked from a breast, as with carts, but is taken out in successive layers from the full area of the cut.

The scrapers are loaded while the teams are moving, and as they are continually in motion, their rate of speed will be somewhat slower than with carts or wagons. Taking the rate of movement of scrapers at 150 feet per minute, the distance traveled in going and coming will be but 75 feet per minute, or 75 feet of lead per minute. Besides the actual length of lead, each team will travel about 25 feet additional in turning and dumping. Hence, the number of trips for each wheeled scraper per day will be the total number of minutes in a working day, viz., 600 divided by the number of 75 feet lengths in the lead + 25 feet, and supposing, for example, there is a total lead of 800 feet, the number of trips per scraper per day will be $\dfrac{600}{\frac{825}{75}} = \dfrac{600}{11} = 54.54$ trips per day, and the number of cubic yards for each scraper will be $\dfrac{54.54}{2} = 27.27$ cubic yards per day.

It will cost an average of 1 cent per cubic yard to loosen soils and 1 cent per cubic yard to load and dump them. An additional charge of $\frac{1}{10}$ cent per 100 feet of lead must be made for keeping the road in order.

Spreading, water carrier, and superintendence will cost 2 cents per cubic yard. A man and team will cost $3.50, with 50 cents added for snatch team, making $4.00 per day, the charges against each scraper for hauling. We have, therefore, the cost of hauling $\frac{\$4.00}{27.27} = 14.67$ cents per cubic yard.

For handling ordinary earthy material with wheeled scrapers, the amount of the foregoing items of cost will be as follows:

Loosening with the plow........	1.00 cent	per cubic yard.
Loading and dumping..........	1.00 cent	per cubic yard.
Hauling......................	14.67 cents	per cubic yard.
Maintaining road at a cost of $\frac{1}{10}$ cent for each 100 ft. of lead...	.80 cent	per cubic yard.
Superintendence, water carrier, and spreading	2.00 cents	per cubic yard.
Total cost to contractor...	19.47 cents	per cubic yard.
Adding 15% for contractor's profit......................	2.92 cents	per cubic yard.
Cost to R. R. Company.........	22.39 cents	per cubic yard.

1496. Drag Scraper Work.—The **drag scraper** (see Fig. 414) holds from .15 to .25 of a cubic yard of material. The same labor of horse and man is required for the drag scraper as for the wheeled scraper, excepting the snatch team. The team will move at the same rate, viz., 75 feet of lead per minute, but only 15 feet need be added to the lead for dumping and turning. Drag scrapers are rarely used for a longer haul than 400 feet.

FIG. 414.

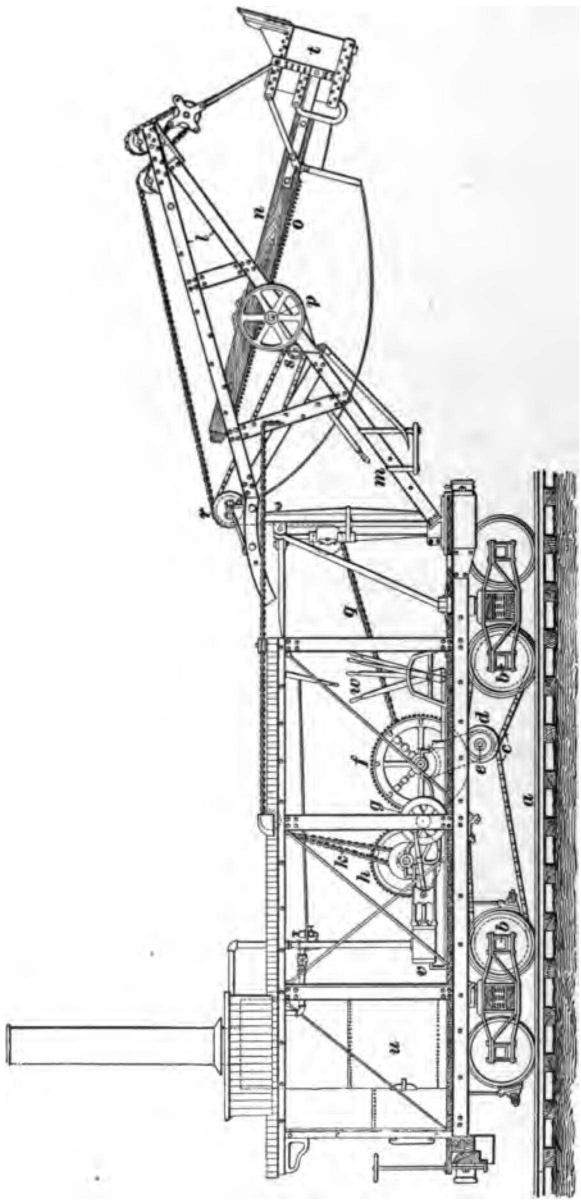


FIG. 415.

The number of trips in a day for a 400-foot lead will, therefore, be $\frac{600 \text{ (number of minutes in day)}}{\text{number of 75 feet length in lead} + 15} = \frac{600}{\frac{415}{75}} = \frac{600}{5.53} =$ 108.5 trips at $\frac{1}{5}$ cu. yd. per trip = 21.7 cubic yards, the amount of material hauled by each team per day. As the team and driver cost \$3.50 per day, the cost of hauling per cubic yard will be $\frac{\$3.50}{21.7} = 16.13$ cents. Other charges will be the same for drag scrapers as for wheeled scrapers, and we have the items giving total cost to contractor for delivering material at the dump, as follows:

Loosening with plow......	1.00 cent per cubic yard.
Loading and dumping.....	1.00 cent per cubic yard.
Hauling..................	16.13 cents per cubic yard.
Maintaining road, $\frac{1}{10}$ cent for each 100 feet of lead...	.40 cent per cubic yard.
Superintendence, water carrier, and spreading....	2.00 cents per cubic yard.
Total cost to contractor, exclusive of profit.....	20.53 cents per cubic yard.
Add 15% for contractor's profit.................	3.08 cents per cubic yard.
Total cost to R. R. Company	23.61 cents per cubic yard.

The above figures are only approximate, and will vary largely with conditions. Much depends upon the material handled, the situation, and the weather; but far more upon the energy, skill, and judgment of the contractor and foreman.

1497. Work with a Steam Excavator and Dump Cars.—In cuttings from 8 feet upwards, a steam excavator may be employed to great advantage. A first-class excavator, such as is shown in Fig. 415, will excavate and load into dump cars 600 cubic yards per day.

The excavator stands on a track *a*, and as the material ahead of the machine is cut away, the track is extended and the excavator is advanced by means of its own machinery. This is accomplished as follows: The car axles *b*, *b* are fitted with sprocket wheels driven by pitch chains *c*. These chains work on sprocket wheels *d*, fixed to the countershaft *e*. The countershaft carries a pinion, not seen in the drawing, which is driven by the large spur *f*, which is itself driven by a pinion attached to the main shaft *g*. The main shaft also carries another pinion which drives the spur *h*, and the drum attached to its shaft. This drum carries the chains *k* which give to the crane *l* its lateral motion. The boom *m* is formed of heavy steel angles, between which the dipper handle *n* works. The power for crowding the dipper outwards is applied through the steel rack and the pinion attached to the dipper shaft, and derived from the hoisting chain *q*, where it passes over a pocket sheave *r*. This pocket sheave drives the intermediate shaft *s* by friction clutch and steel pitched chain.

The dipper *t* holds from 1 to 1¾ cubic yards. The teeth are of heavy pointed steel and attached so as to be renewable. The handle is of oak with racking of heavy cast steel. Steam is generated in the boiler *u*, and the machinery is driven by the engine *v*. The reversing levers are shown at *w*. The excavator crew consists of three men, viz., an engineer, foreman, and craneman. The duty of the latter is to see that the excavator does full work, i. e., that the dipper is filled at each cut of the machine. Six pitmen are required to lay track, see to the shifting of the machine, and help in shifting cars and making up train loads. The bulk of the work connected with the shifting of cars and making up of trains is performed by horsepower.

A pit foreman takes charge of all work not immediately connected with the working of the excavator. The cost of an excavator is about $6,000. For interest on same and wear and tear of machine, charge $10.00 per day.

The several items of cost to be charged to the excavator will be the following:

Cost of excavator	$10.00 per day.
$1\frac{1}{2}$ tons coal @ $6.00 per ton	9.00 per day.
Water	4.00 per day.
Oil, waste, etc	3.00 per day.
Engineer	4.50 per day.
Fireman	2.00 per day.
Craneman	3.00 per day.
6 pitmen @ $1.50	9.00 per day.
Foreman	3.00 per day.
Horse and driver for shifting cars	2.25 per day.
Total	$49.75

At 600 cubic yards per day, the cost per cubic yard for excavating will be $\frac{\$49.75}{600} = 8.29$ cents.

Teams will haul 6 cars holding $1\frac{1}{2}$ cubic yards each and travel at the rate of 3 miles per hour, or an average of about 260 feet per minute, which will be an average of 130 feet going and coming, i. e., 130 feet of lead per minute. About 3 minutes are consumed in stopping, dumping, and changing team for return to the excavator. It will require about $1\frac{1}{2}$ minutes per car to load, making 9 minutes per train of 6 cars. The number of trips per team per day will, therefore, be equal to 600, the number of minutes in a working day of 10 hours, divided by 9 minutes, the time of loading + 3 minutes, the time of unloading + the number of 130 feet lengths of lead. Calculating upon a haul of 1,300 feet equal to ten 130 feet lengths of lead, we have the number of trips per team per day $= \frac{600}{9 + 3 + 10} = 27.3$. Deducting for delays caused by defective track, derailed cars, etc., 3.3 trips, we have 24 trips per day for each team. As each train carries 9 cubic yards, the total yardage per team per day is $24 \times 9 = 216$ cubic yards. The team and driver will cost $3.75 per day. The cost for hauling will, therefore, be $\frac{\$3.75}{216} = 1.74$ cents per cubic yard. Five men are required to maintain the tracks and take charge of the dump, 4 men at $1.25

per day and foreman at $2 per day, making $7.00 per day. The cost per cubic yard for track and dump charges will, therefore, be $\frac{7.00}{600} = 1.17$ cents per cubic yard. It will require 24 cars to handle the materials, at a cost of 50 cents per car per day, making a total daily charge of $12.00, which, divided by 600, gives an additional charge of 2 cents per cubic yard for use of cars. The total cost to the contractor for excavating, loading, hauling, dumping, and spreading will, therefore, be as follows:

Excavating and loading	8.29 cents per cubic yard.
Hauling	1.74 cents per cubic yard.
Care of track, dumping, and spreading	1.17 cents per cubic yard.
Use of cars	2.00 cents per cubic yard.
Total cost to contractor	13.20 cents per cubic yard.
Adding 25% for contractor's profit	3.30 cents per cubic yard.
Cost to R. R. Company	16.50 cents per cubic yard.

On account of the great cost of plant and heavy contingent expenses, the contractor should calculate on a profit of 25 per cent. when making estimates on this class of work.

1498. Rock Excavation.—A cubic yard of hard rock in place, i. e., before being blasted, weighs on an average 1.9 long tons, or 4,256 lb., equal to 158 pounds per cubic foot. A cubic yard of hard or solid rock *when broken up by blasting* so that it may be loaded into carts will occupy about 1.8 cubic yards of space, or 48.6 cubic feet of space. Each cubic foot of broken rock will, therefore, weigh $\frac{4,256 \text{ lb.}}{48.6} = 87.6$ lb. A cart will carry about $\frac{1}{5}$ of a cubic yard of solid rock, i. e., 9.7 cubic feet of broken rock, which will weigh on an average 850 lb., which is only 50 lb. more than an average cartload of earth. A horse may, therefore, be expected to haul as many loads of broken rock as of earth. It will cost on an average 40 cents per cubic yard *in place* to cover the cost of loosen-

ing, including sharpening tools, drilling, powder, etc. It will cost an average of 10 cents per cubic yard in place to load the stone into carts. As the number of cubic yards of rock handled per day is less than the number of cubic yards of earth, the cost of superintendence and of water carrier will be greater, say 3 cents per cubic yard. Repairs of road will cost $\frac{1}{5}$ cent for each 100 feet of lead. Dumping and spreading will cost 2 cents per cubic yard. Carts will cost same as in earth excavation, viz., $1.50 per day. It will require an average of 5 minutes to load and dump carts.

EXAMPLE.—For a lead of 600 feet, what will be the cost to the contractor for delivering solid rock on the dump?

SOLUTION.—The number of cart trips per day will be 600, the number of minutes in a working day, divided by 5 + the number of 100 feet lengths of lead. We have, accordingly, number of cart trips per day $= \frac{600}{5+6} = 54.5$ trips. At $\frac{1}{5}$ cubic yard per cart, the number of cubic yards hauled per cart per day will be $\frac{54.5}{5} = 10.9$ cubic yards in place. The cost of hauling will, therefore, be $1.50, the cost per day per cart, divided by 10.9, the number of cubic yards hauled per cart, which gives 13.76 cents per cubic yard in place, that is, of *solid rock*. We have then for handling solid rock with carts, the following items of cost, viz.:

Loosening	40.00 cents per cubic yard.
Loading	10.00 cents per cubic yard.
Hauling	13.76 cents per cubic yard.
Dumping and spreading	2.00 cents per cubic yard.
Superintendence and water carrier	3.00 cents per cubic yard.
Repairs of road	1.20 cents per cubic yard.
Total cost to contractor	69.96 cents per cubic yard.
Add 15 per cent. for contractor's profit	10.49 cents per cubic yard.
Cost per cubic yard to the R. R. Company	80.45 cents per cubic yard.

All stone and detached rock found in separate masses, containing not less than 3 cubic feet nor more than 1 cubic yard, and all masses of rock, slate, or coal, or other rock soft enough to be removed without blasting, are classified as

loose rock and may be handled at about half the cost of solid rock.

1499. Hand Drilling.—Hand drilling is performed in two ways, viz., by **churn drilling** and by **jumping.** A **churn drill** is made of a round iron bar about 1¼ inches in diameter and from 6 to 8 feet in length, having a piece of tool steel a little wider than the diameter of the bar welded to one end of it. This, after being properly hardened and sharpened, forms the cutting edge. In ordinary work, the holes are from 1½ to 2 inches in diameter and from 2 to 4 feet in depth. Holes drilled with the churn drill are usually vertical. In drilling the bench in tunnel work the drills are inclined slightly backwards from a vertical line. In drilling, the churner raises the drill a few inches, turning it slightly in the hole and allowing it to fall. The drill in a free hole rebounds so that but little effort is required by the driller in lifting the drill. An experienced driller will in a working day of 10 hours drill from 5 to 12 feet of 2-inch hole, depending upon the character of the rock. In granite or hard limestone from 7 to 8 feet of 1¾-inch hole is a fair day's work and from 9 to 10 feet in ordinary sandstone. When the hole is more than 4 feet in depth, two men are put to the drill.

The **jumper** is a short drill which is held and turned by a man in a sitting posture while blows from 8 to 12-lb. hammers are delivered upon the head of the drill by two other men called *strikers*. The average depth of a hole per man is considerably greater with the churn drill than with the jumper. The advantage of the jumper lies in its admitting of drilling holes at any angle and in many places where the churn drill could not be worked on account of limited space. In drilling with jumpers, drills of various lengths are used, depending upon the depth of hole. Drill bits require sharpening at each 6 to 8 inches of hole. Great skill is required in tempering in order that the drills may do full duty.

On surface work, good drillers are paid from $1.50 to $1.75 per day. In tunnel work from $1.75 to $2.00 per day.

1500. Percussion Drills.—Percussion drills are usually spoken of as rock drills, and are built to be driven by steam, compressed air, or electricity. They should be designed for hard service, such as sinking shafts and drilling tunnels in the hardest rock. They should strike a hard blow, and be so built as to stand the most severe usage, yet be readily kept in repair with the facilities available in regions remote from machine shops. They must stand up to the work of pounding a hole in the hardest kind of rock at the rate of 150,000 to 200,000 blows a day, with all the shocks and jars which that would mean. The blow should be an uncushioned blow; that is, in steam and compressed air drills, the exhaust, during the forward stroke, should remain open until the blow is struck, and none of the force of the blow should be taken up by a cushion of steam or air in the front end of the cylinder. The bit or drill proper must hit the rock, which is the only proper cushioning, and hit it before the pressure enters the front end. Expansive working of the steam or air in rock drills, as has been attempted, is a mistake. It is permissible and advisable in engines where the length of the stroke is fixed and where the weight of the machine is not of very great account, but in a rock drill the object is to get the hardest possible blow from the smallest cylinder and the lightest machine. The smaller and lighter the machine, the less space required for working and the easier handled. The value of a hard blow in hard rock is well known. The average drill runner is not careful to keep his bits sharp, and it is a common sight to see a rock drill pounding away with a bit which has no edge at all. It then becomes a question of *pounding* the rock to pieces instead of *cutting* it.

A hard blow will do this, while a tappet drill, which has the force of the blow materially checked by the early admission of pressure to form a cushion, will run along at a lively speed, but accomplish very little in proportion to power consumed. Another quality a rock drill must have is the power to pull the bit out of the hole as well as to drive it in, and that when the hole is blocky, crooked, or muddy.

The best rock drills on the market are the Ingersoll-Sergeant and the Rand drills, operating by steam or compressed air, and the General Electric Co.'s drill, operating by electricity. Fig. 416 is a sectional view of one form of a drill using steam or compressed air, without tripod or column.

The principal parts are as follows: *1* is the cylinder. At the right hand or "back" end of the cylinder there is a washer *2*, and a buffer *3*, to receive the piston when it strikes at this end. Immediately behind these are the "rotation washer" *4*, and the "rotating ratchet" *5*, both inside of the back cylinder head *6*. To the left, *7* is the brass "rifle nut," *8* is the "rifle bar," and *9* is the piston. The rifle nut *7* is secured to the piston *9* and slides back

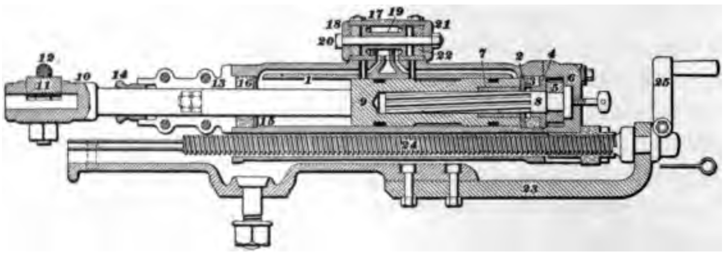


FIG. 416.

and forth with it over the rifle bar *8*. This compels a relative rotation between the bar and the piston, but as the piston is very much the heavier, the tendency is that only the bar will rotate. It is controlled, however, by the rotating ratchet *5*, and allowed to turn only in one direction. The piston, therefore, must turn on its return stroke, and in this way it is made to rotate a little at every blow and so drive the bit to a new place. At the extreme left, 10 is the piston bushing to take the wear off the bit. The key *11* is drawn down by the **U** bolt *12*, and so clamps the bit. The front cylinder head *13* and the gland *14* are both in halves. The washer *15* and the buffer *16* ease up the blow when the piston strikes here. On top we have the steam chest *17*, the steam chest covers *18*, valve *19*, valve guide *20*, valve washers *21*, and buffers *22*. The "goose neck" *23* carries

one end of the feed screw, which is driven by the crank *25* turned by hand.

Fig. 417 represents a drill mounted on a tripod and ready for work. The feed-screw *A* is collared at its upper end to the frame *B* and is thus prevented from moving longitudinally when revolved by the crank fixed to its top. Its lower end works in a nut fixed to the cylinder, which last moves longitudinally backward as the crank is turned.

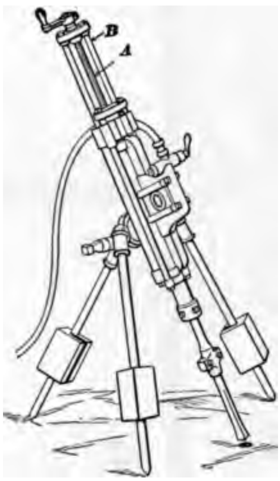


FIG. 417.

The drilling is begun with a short drill called a *starter*, the first few blows being lightly given until the hole is fairly started, when the full force of the steam is turned on. As the drill penetrates the rock, the cylinder is fed forward by means of the feed-screw *A* as far as the shell permits. The steam is then shut off and the drill withdrawn by reversing the movement of the feed-screw. A longer drill is then substituted and the drilling continued. The cutting edges of the bits are necessarily worn by the drilling and constant rotation in the hole so that the diameter of the bottom of each section of hole is slightly less than that at the top; accordingly, at each change of drill, one is selected with a bit from $\frac{1}{8}$ to $\frac{1}{16}$ inch narrower than the one removed.

In *tunnel driving*, the drills used in the heading are usually mounted on columns, similar to that shown in Fig. 418. The column *A* is set in an upright position near the face of the heading, the top *B* of the column being forced against the roof of the tunnel by the capstan screws *C* which rest in special castings *D* on the floor of the heading. It is a common practice to place strong blocks of wood on the head of the column and under the feet of the capstan screws, which prevent the rock supports from becoming loosened by the continued jarring of the column, due to the

working of the drills. The arm *E* at right angles to the column slides up or down the column by means of the collar *F*, and may be clamped in any position by the clamp *G*. The drill is carried on this arm and revolves about it as an axis, thus giving a wide range of action. Usually two drills are mounted on each column. In sinking shafts and driving tunnels, as well as in mine work, compressed air is used instead of steam, which loses much of its pressure through condensation. The use of compressed air greatly promotes ventilation. Percussion drills are *under a pressure* of from 60 to 70 lb. per square inch. *In one hour* one will drill a hole from 2 to 2½ inches in diameter and from 4 to 10 feet in depth, depending upon the character of the rock, the position of the strata, and the size of the machine. The cost of drilling will vary from 8 to 20 cents per lineal foot.

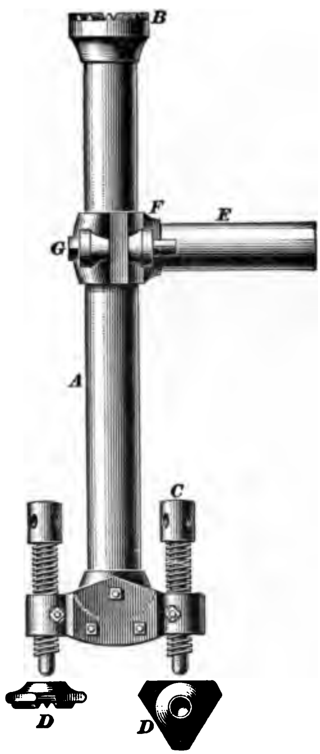


FIG. 418.

1501. Drill-bits are of different shapes, being varied to suit the work to be done. For uniform hard rock, the bit is cross-shaped, with the arms of equal length and at right angles to each other. For seamy rock, the arms of the bits are of equal length, but cross each other **X** fashion. For soft rock, frequently a bit with a **Z**-shaped cutting edge is used.

Fig. 419 shows the usual form of drill-bit, and Fig. 420 the tool for sharpening same. On surface work, a drill is usually worked by one man; in tunnel work, two men are

commonly employed. The man in charge of the drill is called the drill runner and his assistant the helper or tailer. Three or four men are required in moving and placing the larger drills.

FIG. 419.

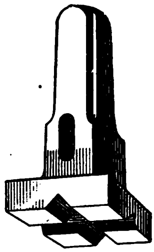


FIG. 420.

1502. Air Compressors.—As before stated, when percussion drills are used for surface work, they are operated by steam which is usually generated in a portable boiler and conveyed to the drills through iron pipes. The direct connection with the drills is made by means of *steam hose*. When the work is of great magnitude and confined to a small area, a stationary boiler of adequate size is set up.

When compressed air is required for working the drills, as in mine or tunnel work, air is forced into a receiver by an

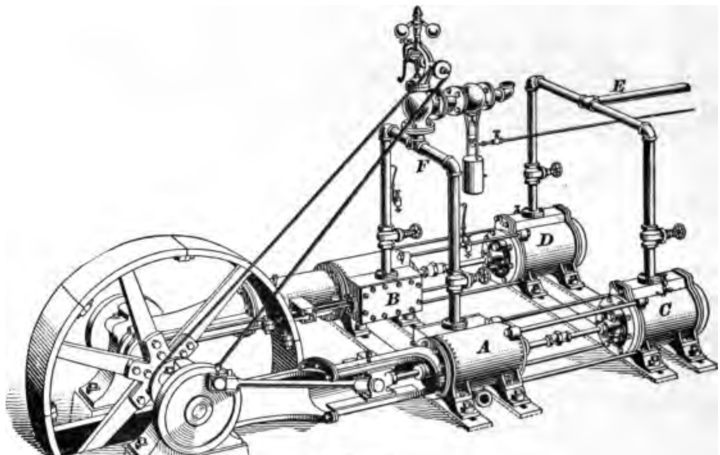


FIG. 421.

air compressor and conveyed thence by iron pipes and steam hose to the drills. The receiver is a wrought-iron cylinder, from 2 to 4 feet in diameter and from 5 to 12 feet long. A cut of a light *duplex compressor* made by the Rand Drill Co. is shown in Fig. 421. It is so made that it can readily be

taken apart and transported on mule-back. *A* and *B* are the steam cylinders, and *C* and *D* are the air cylinders. *E* is the air delivery pipe and *F* the steam pipe. Some of the advantages of the duplex type are the following: Since the cranks are set at right angles, the engine can not get on a dead center. One cylinder can be detached when only half the capacity of the machine is required. The power and resistance being equalized through opposite cylinders, large fly-wheels are not necessary.

A **horizontal air receiver** is shown in Fig. 422. The air enters the receiver at *A*, flows through a series of pipe coils, and discharges through *B*. Cold water constantly cir-

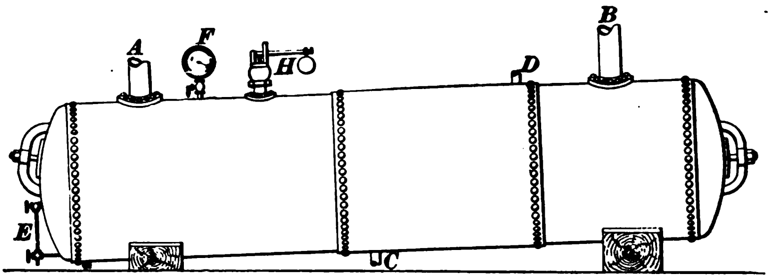


FIG. 422.

culates about these coils, cooling the air and drying it at the same time, the moisture dropping to the bottom of the coils. The glass gauge *E* indicates the amount of moisture deposited. When the gauge indicates too great an accumulation of water, it is drained off. The cooling water enters the receiver at *C* and is discharged at *D*. The gauge *F* shows the pressure of the air, and *H* is a safety valve which regulates the pressure.

RAILROAD CONSTRUCTION.

(CONTINUED.)

TUNNEL WORK.

1503. Tunnels.—The location and construction of tunnels are so intimately connected that it has seemed best to consider them under the head of construction alone.

When grading requires a cutting to exceed 60 feet, it becomes expedient to drive a tunnel. Tunnels should, when possible, be driven on *straight lines*, especially for *single-track* roads, in order to reduce the danger of *collisions*.

1504. Laying Out the Surface Line.—The first work of the engineer in preparing for tunnel work is to lay out the tunnel line on the surface of the ground. If the tunnel line is a tangent, it should be run in by foresights, so far as possible, in order to obviate those errors due to defects in the adjustment of the transit, and the work repeated a sufficient number of times to insure a true line. As a perfect line is of the utmost importance, great pains should be taken, and considerable expense may be incurred in securing long sights. Special transits, called *tunnel* transits, of double the weight and power of ordinary instruments, are used in running the lines. Frequently, platforms of either timber or masonry, several feet in height, are erected at the successive points on the line, their elevation admitting of much longer and clearer sights. The hours of the early morning are the most favorable time for running the test line. The air is then of uniform temperature, and the rays of the sun so low as not to interfere with sights. It is useless to attempt work of this kind when the wind is blowing. A cool, cloudy morning is the best time, and in most situations it may be

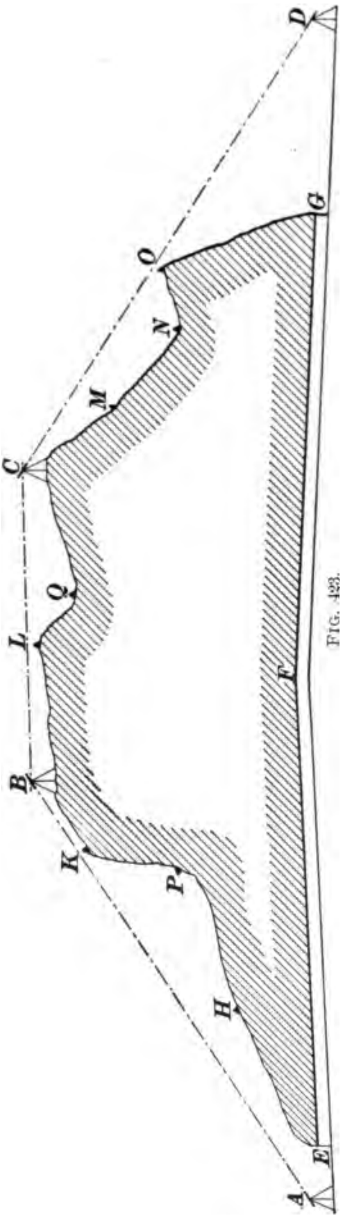


FIG. 423.

had by watching one's chances. Some engineers prefer to run the surface line (if it is one continuous tangent) at night, using plummet lamps for sights. The center line of the Cascade tunnel, on the Northern Pacific Railroad, was run in this way. The laying out of the surface line is illustrated in Fig. 423.

Let *E B C G* represent the profile of the hill or mountain to be tunneled. Setting up the instrument at *A* and foresighting to *E*, a point is set at *B*, the highest point on the surface line which can be seen from *A*. Intermediate points *H*, *P*, and *K* are also set from *A*. Moving the instrument to *B*, a backsight is taken to *A* and a second principal point set at *C*, an intermediate point being at *L*. Removing the instrument to *C*, a backsight is taken to *B*, an intermediate point set at *Q*, and a fourth principal point set at *D* in the opposite tunnel approach. Intermediate points *M*, *N*, and *O* are also set from *C*. This surface line may be from 2,000 to 10,000 feet in length, and yet not have more than half a dozen intermediate points. Frequently the surface is so broken as to require more. The instruments require the most careful and repeated ad-

justments. Mountainous country is especially favorable for making careful adjustments, on account of the long sights which are easily obtained in such localities. Substantial monuments should be set at each of the principal points. A short section of log, cut off square, or a section of sawed timber of equal length, set on end in a pit and bedded in cement mortar rubble, answers this purpose well. The timber should extend three inches above the surface of the ground.

On each monument two points are set about four inches apart. At one of these points a vertical hole one inch in diameter by six inches in depth is bored to hold the per-

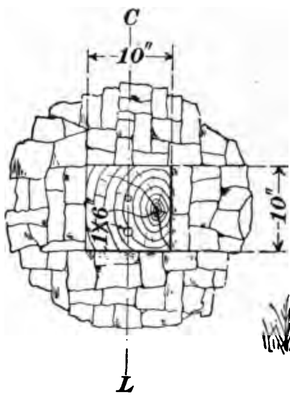


FIG. 424.

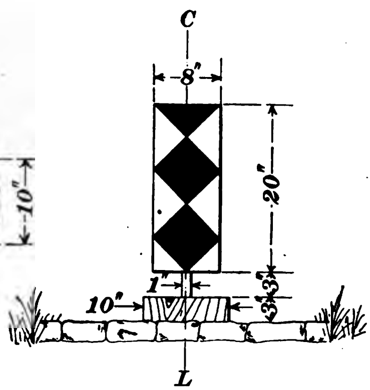


FIG. 425.

manent target, which is set up at each of the principal points. A monument corresponding with the above description is shown in Fig. 424, and target in Fig. 425.

The target is made of pine or spruce. The shank which fits the hole in the monument and the target are of one piece. The surface of the target is divided as shown in Fig. 425, the inner figures painted either red or black and the outer figures white. The target is set up **plumb,** the points of the squares of different colors uniting in a *vertical line* which *coincides* with the *established center line* denoted in both figures by the letters *C L*. Such a target can be readily distinguished with a good instrument at a distance of one mile, and is easily and cheaply made.

1505. Measuring the Line.—After the line is established, it is measured, a work requiring great care and repeated checking. Either of the following methods may be used to obtain horizontal or true measurement: The first method is by the use of a steel tape, plumb-bobs, and spring balance, in which the tape is held in a horizontal position and strained to the same tension at each measurement, the strain being measured by a spring balance. There will be, of course, no uniformity in the length of the sections of line measured, the varying lengths depending mainly upon the degree of the slope. Before the measuring is commenced, stakes are firmly set on line at such distances apart as will permit easy plumbing. A 100-foot standard tape is used, unless the sections are very short, when a 50-foot tape is used. Tacks with small heads are set on line in each stake. In measuring, an allowance of .0000066 part of the length per degree is made for expansion or contraction, according as the temperature at the time of measurement is above or below the normal temperature, which will of course vary in different latitudes.

EXAMPLE.—If a temperature of 50° is assumed as normal and at a temperature of 90° a line measures 72.421 feet, what is its normal length?

SOLUTION.—$90° - 50° = 40°$. $40 \times .0000066$ (the rate of expansion per degree) $= .000264$, the amount of expansion for each unit of length of line. The line measures 72.421 feet. The total expansion will, therefore, be $.000264 \times 72.421 = .019$ ft. 72.421 ft. + .019 ft. = 72.440, the normal length of the line.

For measurements of 100 feet or less a tension of 16 pounds is sufficient. This process of measuring is illustrated in Fig. 426.

The head tapeman holds the zero end of the tape with the spring balance attached at *B*.

The hind tapeman, standing at *A*, holds the tape above the stake until it is in a horizontal position. The tape carries a *rider* containing a spirit level and a small eye through which the plumb-bob cord is passed. There are two rear tapemen. One holds the tape and gives it the

requisite tension, which is reported by the head tapeman at B; the other directs the raising or lowering of the tape while bringing it into a horizontal position, adjusts the plumb-

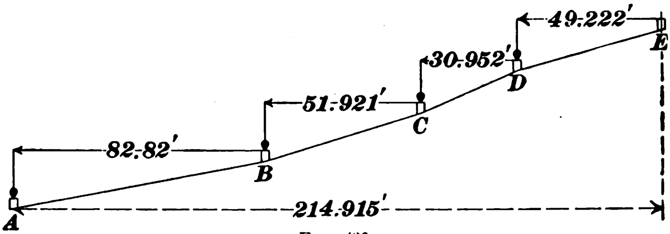


FIG. 426.

bob, and reads the tape. The reading is then recorded. The rear tapemen then change places and repeat the work and record the measurements. Each man must read and

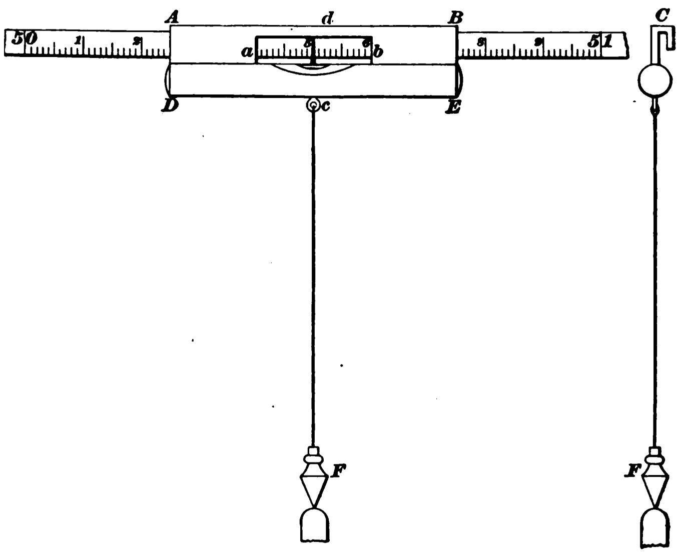


FIG. 427.

record his measurements independently of the other, in order that they may the better check each other's work. Accordingly they do not call out the measurements, but after each

has read and recorded his measurements, they compare results, and if there is any considerable discrepancy, the work must be repeated.

Fig. 427 shows form of tape rider for plumbing tape. It consists of a piece of sheet brass *A B*, 6 inches in length, an end view being shown at *C*. It is bent so as to fit closely to the sides and top of the tape when stretched, and slides along the tape. An open slot *a b*, 2 inches in length, in the side of the rider shows the graduations on the tape. A spirit level *D E* is attached to the under side of the rider. To the under side of the bubble tube at its middle point an eye *c* is attached, from which the plumb-bob *F* is suspended. Directly over this eye and fastened to the rider is a fine point *d*, which indicates to the tapemen the precise reading of the tape.

The second method of measuring is as follows: The stakes are driven as in the first method, and the slope measurements from center of tack to center of tack are taken, the spring balance used, and allowance for expansion or contraction made as in the first method. The levels are then taken between the different stakes, the tack in the top of each stake being taken instead of the surface of the ground, and the slope distances are then reduced to horizontal distances. This method is illustrated in Fig. 428.

The distance $a\ b$ measured on the slope is 68.10 feet, $b\,c = 75.111$ feet, $c\,d = 57.166$ feet. The difference in elevation between a and b is $a\,a' = 16.811$; between b and c is $b\,b' = 20.42$ feet; between c and d is $c\ c' = 20.752$ feet. $a\,a'\,b$ forms a right-angled triangle, right angled at a', in which the hypotenuse is the slope distance, 68.10 feet, and the altitude $a\ a'$ is the difference in elevation between a and $b = 16.811$ feet. From the trigonometrical formula $\sin = \frac{\text{side opposite}}{\text{hypotenuse}}$, we have $\sin\ a\ b\ a' = \frac{16.811}{68.1} = .24686$, whence angle $a\,b\,a' = 14°\ 17'$. The base $a'\,b$, which is the horizontal distance between a and b, is obtained by applying the formula $\tan\ a\ b\ a' = \frac{\text{side opposite}}{\text{side adjacent}}$. Substituting

known quantities, we have $\tan 14° 17' = \frac{16.811}{a' b}$, whence $a' b = \frac{16.811}{.25459} =$ 66.032 feet. By a similar process we determine the length of $b' c$, and find that it equals 72.242 feet, and that $c' d = 53.272$ feet. The total horizontal distance between a and d is the sum of $a' b + b' c + c' d = 191.546$ feet. This method of measurement is possible where the slopes are so abrupt as to render the use of the plumb-bob practically impossible.

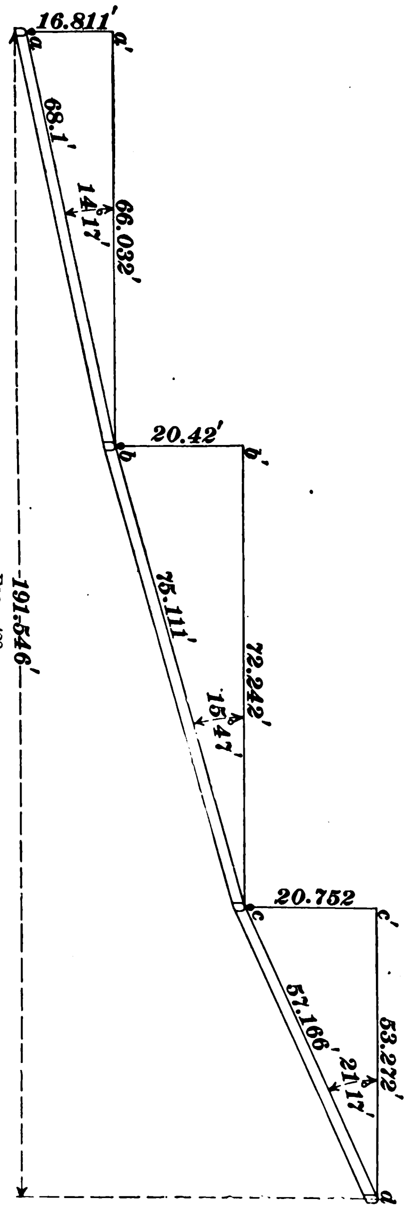


Fig. 428.

1506. Stationing.—Stations are established at each 50 feet, and if the surface be very rough, at each 25 feet, in order that a correct profile of the surface may be obtained.

1507. Curved Tunnel Lines.—When the tunnel line is curved, the tangents are made to intersect, if possible, and the angle of intersection is measured with the

transit. The tangent distances are calculated and the P. C. and P. T. located by direct measurement. The work and calculations are repeated many times, and every possible precaution taken to secure perfect accuracy of results.

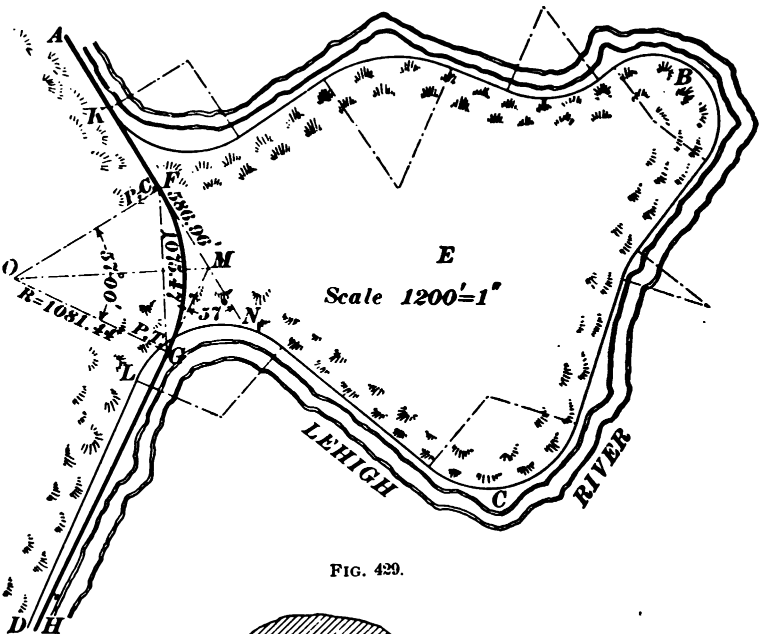


FIG. 429.

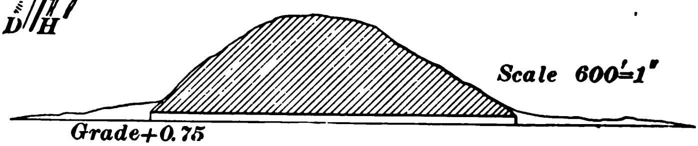


FIG. 430.

The sketch given in Fig. 429 shows the difficulties attending the laying out of the Rockport tunnel on the Lehigh Valley Railroad.

The original line $A\ B\ C\ D$ followed the course of the Lehigh river, which hugs the bluff E. The tunnel line $A\ F\ G\ H$ would have been adopted and the tunnel driven when the road was first constructed, but a rival line was building on the opposite side of the river, and there was a

race to reach the Wyoming Valley coal fields and command the coal traffic. The tunnel line was accordingly postponed and the river line adopted. After a lapse of twenty years the tunnel was driven in 1882–3. The neck *F G* through which the tunnel passes (a profile of which is shown in Fig. 430) reached a height of more than 300 feet. The hillsides were so steep that in places a man could hardly stand. The tangent *K F* is the prolongation of the original tangent *A K*. The grade of the original line was about 20 feet per mile, and as there was a gain in distance of nearly 1½ miles, there resulted a discrepancy in grades at *L* of about 30 feet. In order to dispose of this difference, the grade on the old tangent *A K* and on the tunnel curve was increased to 40 feet per mile. In place of the original tangent *L D*, the tangent *G H* was substituted, and as *G H* has a grade of 40 feet per mile against *L D* of 20 feet, it will be seen that the two grade lines cônstantly approach each other. The difference in grade being 30 feet, it required, at a gain in grade of 20 feet per mile, a distance of 1½ miles for the two grades to meet. The tangents *A K* and *G H* being established, they were produced intersecting at *M*. The intersection angle *G M N* measured 57°. A 5° 18′ curve was decided upon, and the tangent distances *M F* and *M G* measured by direct measurement, and the P. C. and P. T. set.

On account of the steepness of the slopes and the height of the hill, much difficulty was experienced in making a satisfactory intersection. Within a distance of 500 feet there was a difference in elevation of more than 300 feet, and, though taking every precaution, some of the sights contained a vertical angle of more than 60°. The lines were run principally in the early morning hours, though some of the best results were obtained on cloudy days. A large tunnel transit with powerful lenses, and of more than double the weight of an ordinary transit, was used. Common pins against a dark background were used for backsights. First an intersection was made, large plugs (6 inches square) being used. The tangent *K M* was then repeatedly run,

and each line marked on the plugs O and P, Fig. 431, with tacks, each one of which was numbered, as shown in the figure. The lines varied each time, no two coinciding. One or two fell wide of the mark and were ignored. Finally the mean of the lines (as shown by the heavy line in the figure) was adopted as final. The tangent $G\ M$ was then

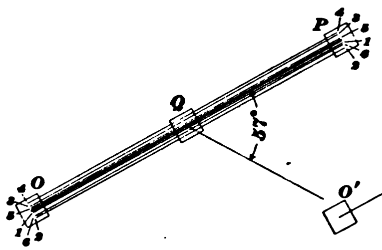


FIG. 431.

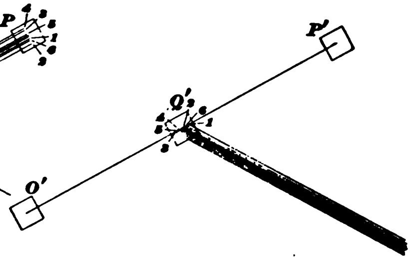


FIG. 432.

run an equal number of times, and each intersection on the line $O'\ P'$, Fig. 432, marked on the plug Q' with a tack and numbered. The mean of these intersections, as indicated by the heavy line, was taken as final.

Equally great difficulty was experienced in locating the P. C. and P. T. The distance was measured many times, and each distance marked. The mean was then taken as the correct measurement. The top of the hill had the form of a plateau, and the center of the curve, O, was located by turning a right angle to the tangent $K\ F$ at F, the P. C., and measuring the radius 1,081.44 feet, locating the center O. The central angle $F\ O\ G$ of 57° was then turned, and the second radius $O\ G$ run out and measured. The line and measurement falling on the plug at the P. T. at G proved the work correct. The reward for all this care and pains was in the almost perfect alinement of the tunnel. The tunnel was driven from both ends, and when the headings met there was found to be less than a half inch discrepancy in the two lines.

1508. Tunnel Sections.—Tunnel sections vary somewhat, according to the material to be excavated, but the general form and dimensions are much the same.

The general dimensions are as follows : For double track from 22 to 27 feet wide and from 21 to 24 feet high, and

Section of Double Track Tunnel.

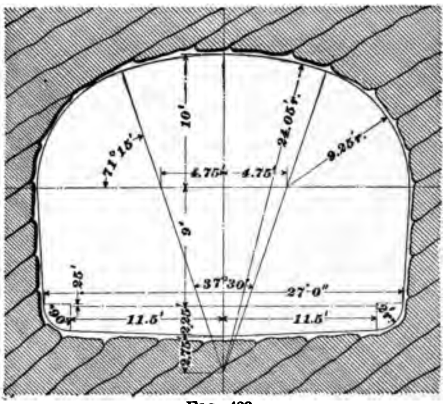


FIG. 433.

Section of Single Track Tunnel.

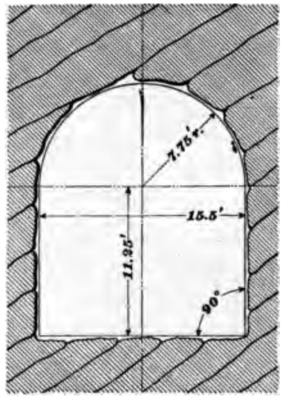


FIG. 434.

for single track from 14 to 16 feet wide and from 17 to 20 feet high. See Figs. 433 and 434.

In seamy or rotten rock the section is sufficiently enlarged to receive a lining of substantial rubble or brick masonry laid in good cement mortar. When the material has not sufficient consistency to sustain itself until the masonry lining is built, resort is had to timbering, which furnishes the necessary support.

1509. Tunnel Driving.—Tunnels in rock are driven either by hand or machine drills. The requirements of modern railroad construction are such that hand drills play a very important part in tunnel work. There are many points in favor of hand drills and hammers, viz., portability, cheapness, and immunity from the accidents which frequently cause delays where machine drills are used. But the process is slow, compared with machine work, and time limitations have made the use of machine drills compulsory.

1510. Plant.—The plant for furnishing the compressed air used in working the drills consists of a boiler house where steam is generated, and an engine house

containing the engines, air compressor, and air receiver. Both houses are usually under one roof. If the tunnel is short, a single plant, situated near one of the tunnel portals, furnishes power for all the machinery used at both working faces. When the tunnel is of great length, an air compressing plant is stationed at each end. About 12 horsepower is required to run each drill (drill cylinders 3⅛ to 3¼ inches in diameter), and as each tunnel face requires six drills, a 70-horsepower boiler and engine is required to work each tunnel face. When the air is conveyed a great distance, there is some loss of power through friction. A three-inch pipe will carry sufficient air for six drills. The pipe couplings are well leaded to prevent waste of air.

1511. Method of Driving.—When the material is rock, the mode of driving is the following: The tunnel section is divided into two parts, viz., the *heading* and the *bench*. The **heading** comprises from one-fifth to one-fourth of the entire section extending from the roof downward. It is from 6 to 8 feet in height, and is kept from 50 to 250 feet in advance of the remainder of the section, which is the **bench.** The drills working in the heading are mounted upon columns, two drills on each column. The drills working on the bench are mounted upon tripods. The air pipe is carried to within about 50 feet of the bench, where a bench hose of equal diameter is attached to the air pipe, leading directly to the bench. At the end of the hose is a metal nozzle called a manifold, containing hose connections for each of the drills.

A section of heading showing arrangement of drill holes in the face is given in Fig. 435. The two middle rows of holes AB and CD converge at an angle of about 20°, nearly meeting on the center line EF of the tunnel, and are called the **center cut holes.** The mass of rock included by these holes is wedge-shaped and shown in plan at A in Fig. 436. The removing of this wedge by blasting is called **breaking the cut.** Fig. 437 shows a longitudinal section through the center cut holes. The rows of holes G, H, K,

and *L*, Fig. 435, on each side of the center cut holes, are called **side rounds.** If but one row on each side, they are

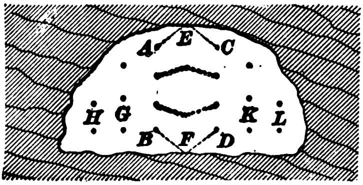


FIG. 435.

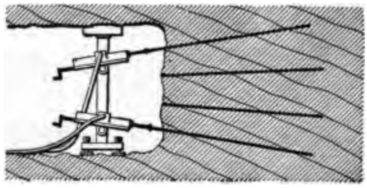


FIG. 437.

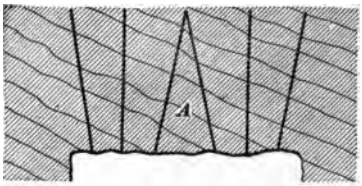


FIG. 436.

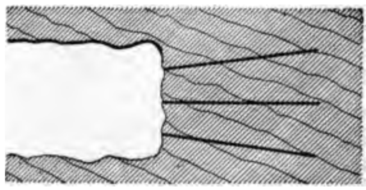


FIG. 438.

called **single side rounds;** if two rows, **double side rounds.** A longitudinal section through the side holes is

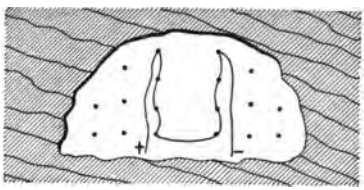


FIG. 439.

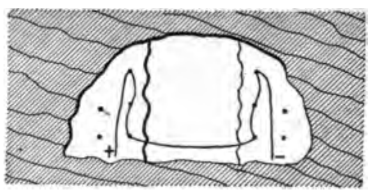


FIG. 440.

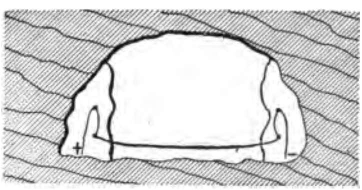


FIG. 441.

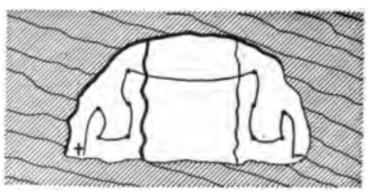


FIG. 442.

given in Fig. 438. The *cut* and *side rounds* are loaded at the same time. The cut is fired first (see Fig. 439), followed

by the side rounds, which are fired either single, i. e., one row on each side of the cut (see Figs. 440 and 441), or double fired, i. e., both rows fired simultaneously, as shown in Fig. 442.

1512. Enlarging the Heading.—In that portion of the heading shown in the preceding figures, the holes are drilled directly into the face of the heading. After the holes are fired and the material removed, side holes are

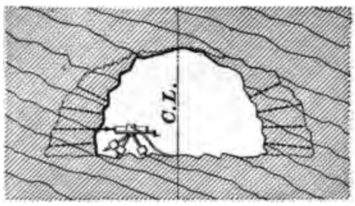


FIG 443.

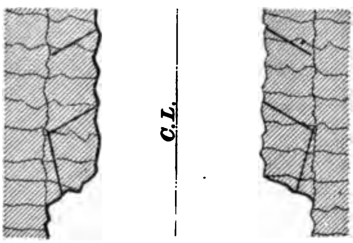


FIG. 444.

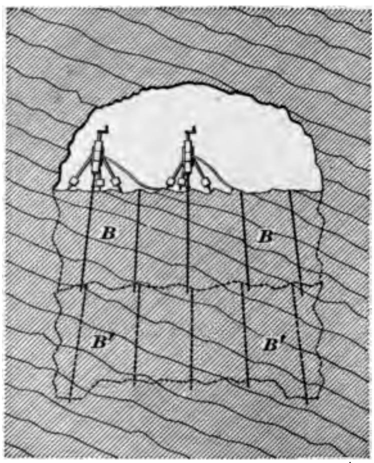


FIG. 445.

drilled at an angle of about 60° with the center line denoted by the letters *C. L.*, as shown in section in Fig. 443 and plan in Fig. 444.

1513. Removing the Bench.—The bench is taken out in two sections, *B* and *B'*, as shown in section in Fig. 445. The full tunnel section is shown by dotted lines.

The holes in the bench are inclined backward from a vertical line. A longitudinal section through the center line, showing the usual mode of drilling headings and benches, is given in Fig. 446. The center cut holes in the heading *H* and all the bench holes at *B* and *B'* are usually fired

together, followed by double side rounds in the heading. The center cut offers the greatest resistance to blasting. The holes are consequently loaded with more powerful explosives than are used for either side rounds or bench.

In driving the New York aqueduct tunnel, the cut was loaded with dynamite containing from 60 to 80 per cent. of nitro-glycerine, while the average bench powder contained but 40 per cent. of nitro-glycerine. On some sections, where rock of special hardness was encountered, the cut was loaded with pure nitro-glycerine. This operation is

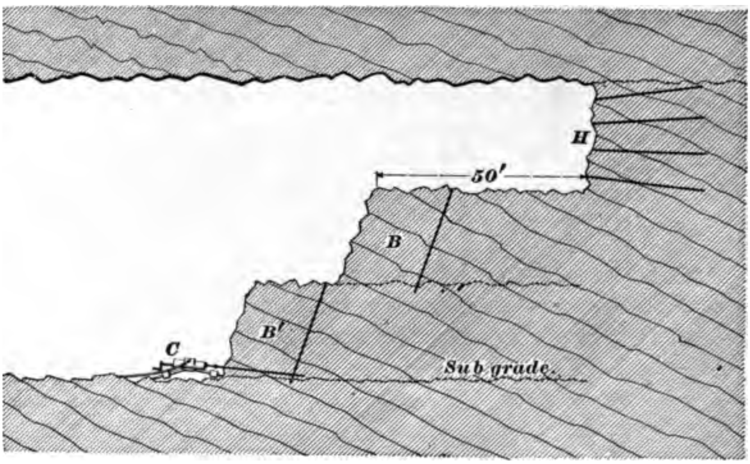


FIG. 446.

always attended with great danger. After several premature explosions, resulting in considerable loss of life, the use of pure nitro-glycerine was abandoned. The effect of firing the cut is generally to pulverize the rock, and all tunnel blasting is intended to so break the rock as to render the use of the sledge-hammer unnecessary in reducing masses of rock to sizes convenient for loading.

The execution of the powder depends largely upon the judgment used in locating the holes and the angle at which they are bored. The position of the machine while drilling holes at foot of the bench is shown at *C*, Fig. 446.

1514. Drainage.—The grade of a tunnel must be established with reference to securing complete drainage. When the grade at both portals is the same, the grade of the tunnel is made to ascend from both ends, the grades being united by a flat vertical curve. The grade of the St. Gothard tunnel is 0.1 per cent.; that of Mt. Cenis 0.05 per cent., but these grades are very light. A grade of 0.25 per cent. will insure complete drainage and need not be exceeded. If the tunnel is short, a continuous grade may be employed. In such a case, if the tunnel is driven from both ends, it will be necessary to remove the water from the descending portion by pumping. In tunnels of considerable length, the grade is usually made to ascend from both ends. This provides complete drainage during construction and also reduces the cost of removing the excavated material, as the loaded cars will either run of themselves or with small draft. When shafts are sunk, the water is removed from the tunnel by pumping.

1515. Shafting.—When the tunnel is of considerable length, and dispatch in driving is of great importance, additional working faces are obtained by sinking one or more shafts, each shaft affording two additional working faces. Shafting adds very considerably to the cost of tunnel driving; for, besides the cost of sinking the shaft, there is the constant expense of hoisting the excavated material to the surface, to which must be added the expense of pumping. On the New York aqueduct tunnel, which has a total length of about 33 miles, a shaft was sunk at each interval of one mile, the shafts varying in depth from 80 to 380 feet. Where shafts are employed, the greatest care and skill are necessary in transferring the alinement from the surface of the ground to the tunnel at the foot of the shaft.

1516. Shaft Lining.—When the shaft is sunk through solid rock, the walls are self sustaining, and no timber lining is required except a curb at the top of the shaft. If, however, the material is earth, loose rock, or shale, the shaft must be timbered. The timbers are put in place as the shaft is sunk.

Frames (*sets*, they are commonly called) of timber, shown at *A* in Fig. 447, are placed about 4 feet apart, and behind these frames, lagging *B*, of either sawed timber or half round poles split from young trees, is placed on end and in close contact. As each frame is placed in position it is supported by struts footing on the bottom of the shaft, or if the walls are sufficiently firm, the frames are held in place by wedges,

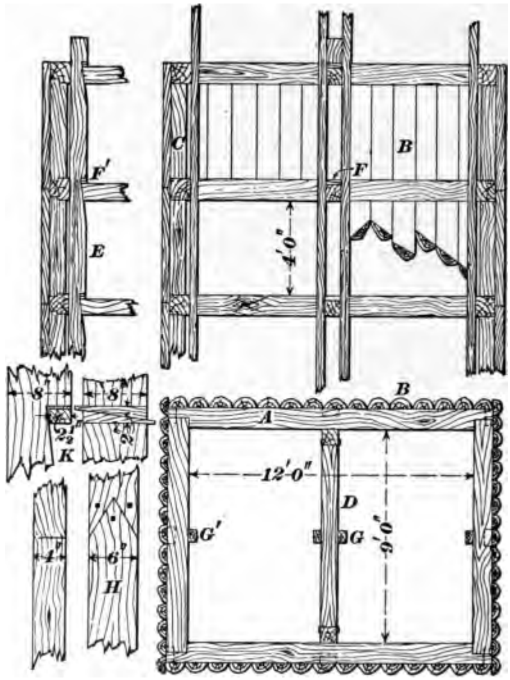


FIG. 447.

until another set is required, when timber struts *C*, mortised into the frames, form the permanent support. These struts are placed one above the other, and, together with the frames into which they are mortised, form continuous timber columns extending from the bottom to the top of the shaft. With each set of timbers a horizontal timber *D*, called a **bunton,** is placed with ends abutting against the

vertical timber *E*. A beveled seat with a square shoulder is cut on the vertical timber for each bunton. The buntons are held in place by wedges shown at *F* and *F'*. These wedges are forced between the bunton and the shoulder of the beveled seat. As the wedges are tightened, the bunton is forced downwards until it is perfectly rigid. Vertical timbers *G*, *G'* are spiked to the buntons and to the ends of the frames, to serve as guides for the carriage. A detail of the splice of the carriage guide is shown at *H* and of the wedges at *K*. As all shafts are moist, and many decidedly wet, iron should only be used in timbering when no substitute can be found. The pressure of earth or loose rock against the timbers is usually sufficient to hold them in place, and most of the joints do not require keying. Treenails (wooden pins) should be used in place of iron. The lagging must be put in place as fast as the work progresses, and all spaces behind it filled with well-rammed earth. In very wet ground or in quicksand, special devices are employed to meet the needs of the situation. Shaft sinking in bad ground is exceedingly dangerous work, and every known precaution is essential if loss of life would be avoided.

1517. Removing Excavated Material.—The material excavated in tunnel driving is called **muck.** The muck is loaded into dump cars at the foot of the bench, which, when there is a sufficient descending grade, run by gravity either to the foot of the shaft, where they are hoisted to the surface, or to the dump outside the tunnel. When there is not sufficient grade to run the cars of themselves, mules are employed to haul them.

A single track *A*, Fig. 448 (ordinarily of 3 feet gauge), is laid on the center line of the tunnel, with passing branches at suitable intervals. At a distance of about 100 feet from the bench a simple switch is built, and two tracks *C* and *D* laid to the bench, which permit the loading of two cars at the same time, and provide for shifting cars. On a level with the top of the bench, and directly over the cars, a scaffold *E* is erected, and upon it a runway of planks *F* is laid,

extending from the scaffold to the heading. The heading muck is loaded into barrows and wheeled on this runway to the scaffold, and emptied directly into the cars.

A simple and very effective bench scaffold is made of wrought iron pipe supports and shown in Fig. 448. Each support consists of two pieces of pipe, one telescoping within

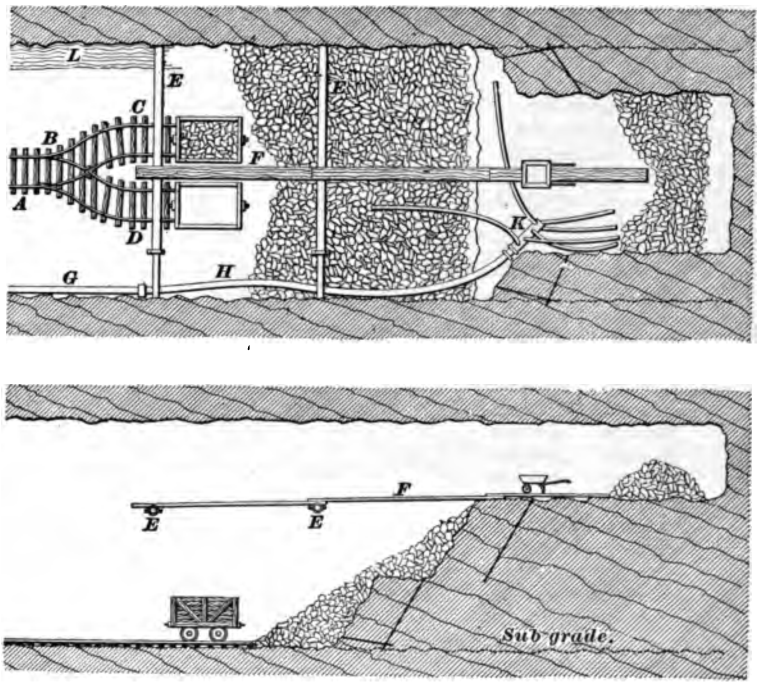


FIG. 448.

the other, and provided with clamps by means of which they are adjusted to any desired length. The plank is laid directly upon these pipe supports. The air for working the drills is carried from the air pipe G to the bench by means of the bench hose H. The manifold K attached to the end of the bench hose contains hose connections for all the drills. A ditch L on the opposite side of tunnel from the air pipe drains the tunnel.

As the work advances from the tunnel entrance, or from the foot of the shaft, more time is required to haul away the loaded cars and bring back the empty ones. When one mule is no longer able to perform the work a second one is added, and passing branches are built in the main track at suitable intervals, where returning empty cars are switched while the loaded cars are passing outward. A passing branch contains two switches, which are made self-acting by the following simple device, shown in Fig. 449. The points of the switch rails *a* and *b* are connected by a clamp rod, attached to a spring *c d*, which is constantly acting, and holds the point *a* close against the main rail *c f*, and the switch is constantly set for the passing branch *k l*. The switch points *m* and *n* of the second switch are kept in place by the spring *o p*, the switch being always set for the main track *q r*. An outgoing car running in the direction *r q* finds the switch *Y* set for the main track. Upon reaching the switch *X*, the flange of the right-hand wheel, passing between the rail *c f* and the switch point *a*, forces the switch point *b* against the rail *s t*, and the car passes the switch in safety. A returning empty car finds the switch *X* set for the passing branch *k l*, and in passing from the branch to the main track, the flange of the head wheel, in passing between the rail *n t* and the switch point *m*, forces the switch point *n* against the main rail *c f*, and the car passes safely on to the main track. The springs *c d* and *o p*

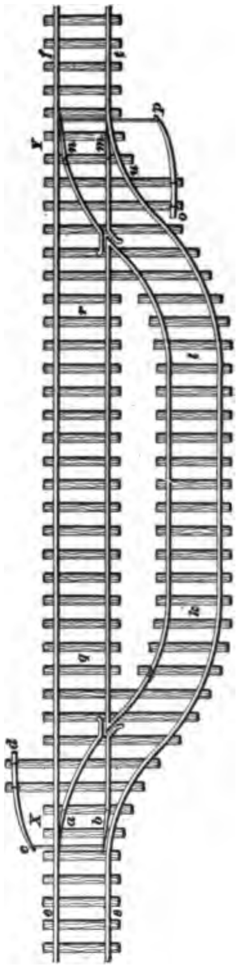


Fig. 449.

are elastic young saplings, kept in place by strong staples driven into the switch ties.

1518. Care of Track.—A common fault of contractors and their employes is *neglect of track.* Usually poor material is furnished, worn out and crooked rails, poor fastenings, poor ties, and often no ties, requiring every sort of makeshift. With such material a good track is impossible, and requires constant tinkering. Derailments are continually occurring, involving costly delays. Tunnel tracks should be built of good material and in a thorough manner. Short rails of varying lengths are required in keeping the track well up to the bench. With proper care of tracks, the cars may be kept within easy shoveling distance of the bench. The foreman in charge of the muckers should keep a small stock of ties and rails constantly on hand, together with the necessary track tools, and do his own track work.

1519. Keeping Down to Grade.—The invariable tendency in tunnel work is to keep above grade. The principal cause is the unconscious effort to avoid the water which is constantly accumulating. This tendency can only be avoided by establishing grade stakes at every 25 feet and keeping the excavation on true lines. The holes drilled at the foot of the bench should penetrate a foot below grade, which will insure the removal of the entire section. Much of the muck in the bottom of the tunnel will require severe use of the pick to remove it. Wedges and a heavy sledge are often of great service in this work.

1520. Timbering.—When the material is rotten rock or earth, the tunnel must be timbered. The timbered section should be enough larger than the standard section to admit of a masonry lining. When the material is such that the side walls will stand of themselves for a time, hitches *A* and *B* are excavated near the springing line and sets of timbers placed as shown in Fig. 450. Iron clamps shown at *C* and *D* hold the timbers together while the lagging is

being placed. It is laid over the timbers lengthwise of the tunnel and as close together as possible. The spaces G, H

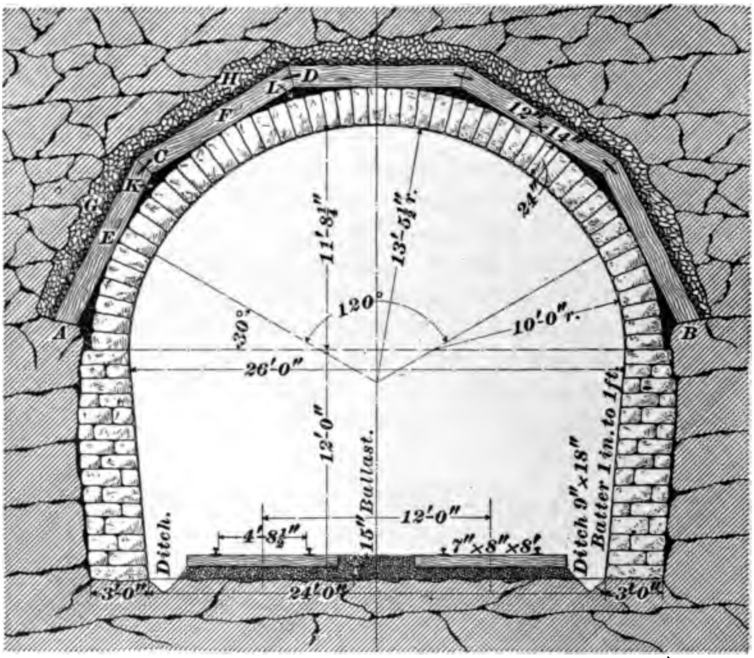


FIG. 450.

between the lagging and the roof are filled with dry rubble or cordwood.

Roof timbers should be either 12 in. × 12 in. or 12 in. × 14 in. in cross-section, and placed with 2 to 4 feet clear space between each set. Where the ground is very soft with a tendency to expand, larger timbers may be necessary. Hemlock, yellow pine, or spruce is commonly used. In special cases, where great pressure is to be resisted, oak is used. When the side walls will not support the roof timbers, they are carried on supports arranged as shown. in Fig. 451. Four posts A, C, D and B, resting on sills O, P, Q and R, are mortised into the cap E F.

The roof timbers G, H, K are clamped together as in Fig.

450, and mortised into the cap at spring line. The pressure against the roof timbers is relieved by the struts *L*, *M*, *N*, *U*, and *V*, which transfer the stress to the posts *C* and *D* and the cap *E F*. The dimensions of timber given in the drawing are such as are used where the pressure is great; they will meet the requirements of most situations. The lagging may be either sawed timber or split poles, obtained by split-

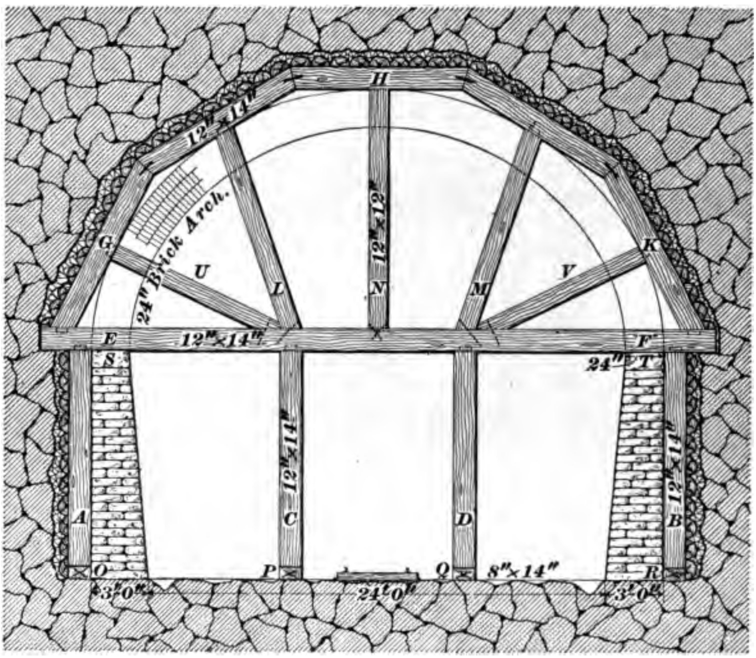


FIG. 451.

ting in half straight grained chestnut or oak saplings. The backing may be either dry rubble or cordwood. The latter is preferable, as it is light, portable, and uniform in shape. The side walls are all of well-scabbled rubble of good-sized stones, even beds, and laid in courses with cement mortar. The impost courses *S* and *T* should be of well-cut stone, twelve inches in thickness and of full width of wall. The arch is either brick or rubble. The caps and roof struts

interfere somewhat with arching. Holes are left in the masonry where these timbers interfere until a section of the arch is complete, when they are removed and the gaps filled with masonry, the joints being thoroughly grouted. All other timbers are left in place. The spaces *K*, *L*, etc., Fig. 450, between the arch and roof timbers, are usually filled with concrete.

When the material through which the tunnel passes is very soft, with slight coherence, all the energy and skill of engineer and workmen are required to make headway. It is considered the better practice to drive the heading at the bottom of the tunnel instead of the top, as by the time

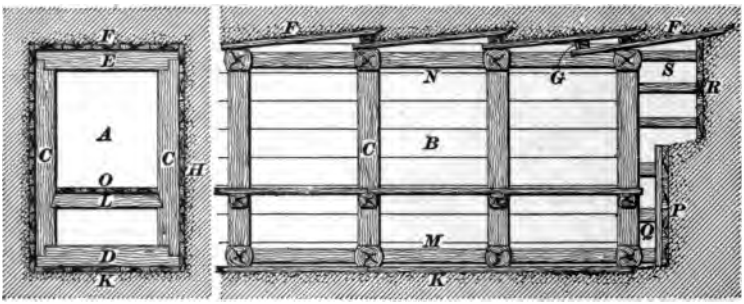


FIG. 452.

the heading is driven the ground composing the remainder of the section will have become thoroughly drained, and may be taken out with much greater safety and less expense than with a top heading. The mode of driving a heading through such material is illustrated in Fig. 452, in which *A* represents a cross-section and *B* a longitudinal section of the heading, with complete system of timbering.

A full section of timbers is called a *set*, of which the upright timber *C* is called the *leg;* the horizontal timber *D* the *sill*, and *E* the *cap* or *collar*. The short boards *F*, *F*, which extend from collar to collar, and are in direct contact with the sustained material, are called *poling boards*. They are sharpened to a cutting edge, and are driven into the face of the heading with sledges, a wedge-shaped block *G* being

placed above them to keep them at a proper angle. The planks H which protect the sides of the heading are termed *lagging*. The flooring K serves to exclude the liquid mud, which would otherwise be forced from underneath by the external pressure. The horizontal cross timber L, as well as the longitudinal timbers M and N, are called *struts*. The floor O serves as a footing for the workmen while driving the poling boards.

If the material penetrated is wet enough to run, it is necessary to constantly maintain a bulkhead of planks P, called face boards, which is held in place by struts Q. As the poling boards are driven forward, the top face board is removed, allowing the released material to flow into the gangway. This forms a cavity in the face of the heading, and immediately another bulkhead is started by placing a face board R in advance of those at P, with a strut S to keep it in place. When the heading is advanced half the length of the poling boards, a new set of timbers is put in place, the collar of which takes the strain from the poling boards, which would otherwise be soon broken by the great pressure above them.

As the section is enlarged, other timbers are substituted, until the complete section is excavated. The masonry lining should follow immediately. The less important timbers may be removed as the masonry advances, and their stresses transferred to it; but the main supports should remain in place, and the masonry be built around them, and not disturbed until the arch is keyed. They can then be removed with safety, and the vacancies in the masonry carefully filled and grouted. All open spaces between the masonry and the timber should be filled with well-rammed concrete.

1521. Centering.—Tunnel centers are built on much the same plan as those used in arched culverts, a full description of which was given in Arts. **1475** and **1476.**

1522. Portals.—Tunnel portals correspond to the face and wing walls of an arched culvert. Usually some

regard is paid to architectural effect, the walls being of dressed stone laid in courses.

1523. Alinement and Levels.—During construction, the alinement and levels must be frequently tested. At least once a week the heading should be carefully centered, and a grade stake set at the foot of the bench.

In running the center line, *plummet lamps* are used instead of the transit poles used on surface lines. A plummet lamp consists of an oil reservoir of brass of the shape of an ordinary plumb-bob, the stem of which contains the wick. The lamp is suspended by a bail, at the crown of which is an eye for the cord which suspends the lamp. When suspended, the cord, the flame of the lamp, and the point of the plumb-bob are in the same vertical line. A man holds the cord against the roof of the heading, moving it right or left until the intersection of the cross wires coincides with the flame of the lamp. A point is then marked on the roof, and a hole accurately drilled by hand to a depth of about three or four inches. A plug of dry pine is then driven into the hole, projecting two inches below the roof. The plug is carefully centered and a screw-eye securely fastened in its center, from which a plummet lamp may be suspended. A piece of copper wire equal in length to the full height of the tunnel is attached at one end to the screw-eye and the other end fastened to the wall of the tunnel.

When the full section of the tunnel is excavated, a plumb-bob is suspended from the wire, just touching the floor of the tunnel. A hole is drilled at the point, plugged, and centered, as on a surface line. For bench marks, holes are drilled in the tunnel wall about two feet above the floor, and plugs of either wood or iron are firmly driven and allowed to project far enough from the wall to allow the rod to be held upon them in a vertical position. In testing the grade of the roof, the rod is held in an inverted position, the foot of the rod being placed against the roof. In this case the elevation of the roof is obtained by adding the rod-reading to the height of instrument. For example, suppose

the tunnel section is 24 feet in height, the floor grade at say Station 160, is 240.5 feet and the height of the instrument, which is standing on the bench, is 259.6 feet, what should the rod read to give roof grade for Station 160? The floor grade at Station 160 being 240.5 feet, the roof grade will be 240.5 feet + 24 feet (the height of the tunnel section) which is 264.5 feet. As the height of instrument is 259.6 feet, the rod-reading for roof grade will be 264.5 − 259.6 = 4.9 feet. A common bulls-eye lantern is used to illuminate the cross hairs, and a small headlight reflector affords the best light for reading the level rod and tape, and for taking notes.

1524. Measuring Excavation. — Various methods are adapted for checking the dimensions of the tunnel section and measuring up the work. The best device is the following, shown in Fig. 453. A semi-circular protractor *A B* of a diameter from 8 to 10 feet, and made of light pine,

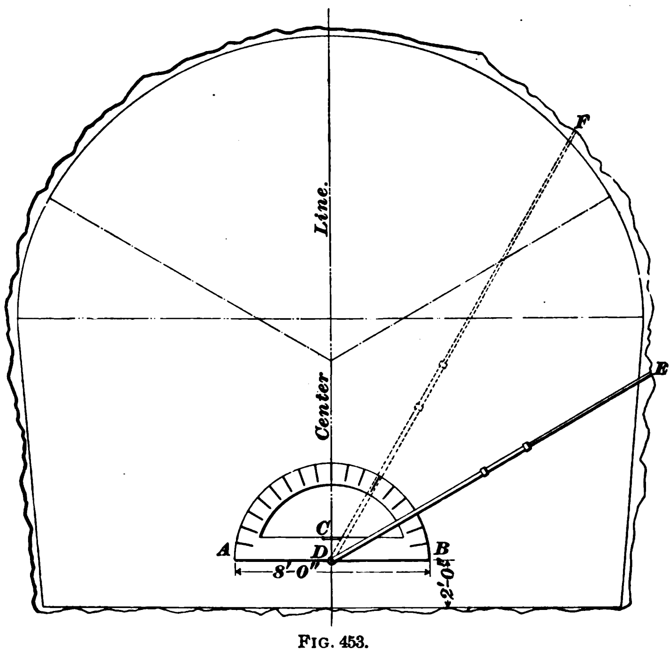


FIG. 453.

is set up at right angles to the center line of the tunnel. The diameter *A B* of the protractor is brought into a horizontal position by means of the spirit level *C* and placed at any desired height above the floor of the tunnel. A sliding rod *D E*, one end of which is fastened to the center *D* of the protractor, measures the distances to the tunnel walls on radial lines. The angles which these lines make with the horizontal are read directly from the protractor. The tunnel section and the actual working measurements are then platted on cross-section paper, from which the amount of excavation is readily calculated.

1525. Plumbing Shafts.—When a shaft is sunk to increase the number of working faces, the process by which the center line is transferred from the surface of the ground to the bottom of the shaft is called plumbing the shaft. Fig. 454 illustrates the process. Two pieces of plank *C* and *D* are spiked to the shaft timbers where the center line crosses, the edges of the plank projecting over the shaft wall.

Slots *E* and *F* are cut in the plank on the center line. An iron plate with a carefully drilled hole in its center is placed over each slot with the center hole exactly on the center line of the tunnel. Holes are drilled in the corners of the plates for screws, by means of which the plates are fastened to the plank.

Plumb-bobs weighing from 20 to 30 pounds are suspended by fine steel wire which passes through the eye-hole in the plate. On the shaft bottom a pail of oil is placed directly under each plumb-bob, which is entirely immersed in the oil to check the vibrations. When the plumb-bobs come to rest, the lines which suspend them are exactly in the center line as laid down on the surface of the ground. A transit is set up at *I* (the tunnel having been driven some distance from the foot of the shaft) and moved until both wires are exactly in the line of sight. A plug is then set on the line at *K*, after which the instrument is moved to *K* and a plug set at *I*, thus establishing the line.

1526. Ventilation. — In clear weather, the gases formed by the combustion of the powder used in blasting pass rapidly from the tunnel to the outer air. In heavy weather, and especially when the heading is at a considerable distance from the portal or shaft, several hours are required to clear the tunnel of powder smoke. Under such

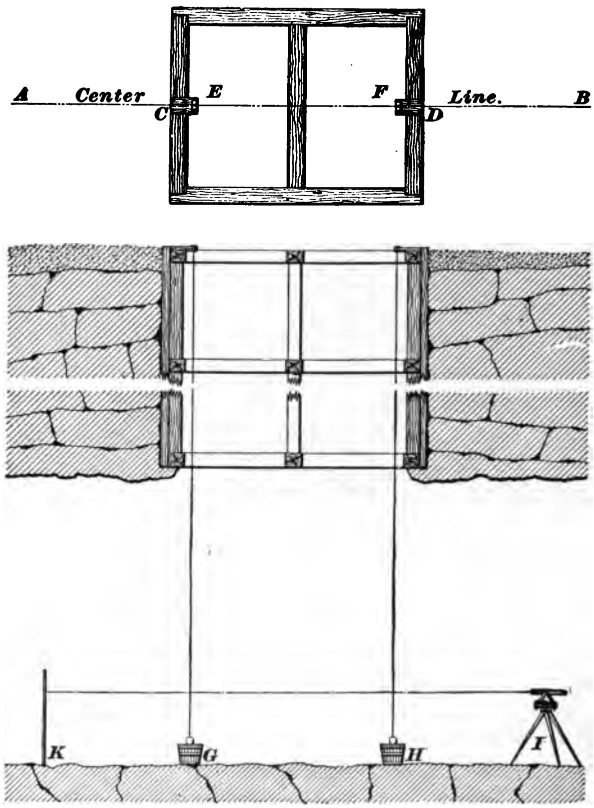


FIG. 454.

conditions the question of ventilation becomes an important one. In order that a man may do effective tunnel work, he should have a supply of 100 cubic feet of pure air per minute. And as there is an average force of 25 men in each

heading, the aggregate supply of pure air per heading should therefore be 2,500 cubic feet per minute. A 70-horsepower compressor will deliver to the drills about 500 cubic feet of free air per minute, and there will still be required for ventilation the difference between 2,500 cubic feet and 500 cubic feet, which is 2,000 cubic feet per minute.

Exhaust fans with air pipes leading to the headings should provide the balance of 2,000 cubic feet per minute. A 24-inch air pipe, carrying air at a velocity of about 10 feet per second, will provide the necessary ventilation. The air pipe should reach as near to the bench as may be without injury from blasts. Contractors are invariably negligent in the matter of ventilation, causing much needless suffering to their men and much loss to themselves. Men can not and will not do full work in a tunnel reeking with powder smoke.

Exhaust fans give much better results than blowers, as they remove the foul air and powder smoke direct from the heading, instead of forcing it out through the shaft or portal, as in the case with blowers.

1527. Cost of Tunnel Excavation.—The cost of tunnel excavation varies widely, depending principally upon the character of the material excavated. Firm rock of moderate hardness can be removed at from $4.50 to $6.50 per cubic yard for the entire tunnel section. The heading will cost about 40 per cent. more than the balance of the section, on account of the limited space for working drills and the greater amount of powder required in blasting. Where unusual obstacles are met, the cost may increase 200 per cent. or 300 per cent. over the above figures. Earthy material is easily broken, but the expense and delay in timbering and lining brings the cost to about the same figures as for solid rock.

1528. A Day's Work for a Machine Drill.—An average day's work for a machine drill in heading or on bench is 50 feet of 2-inch to 2½-inch hole. The great records made on the surface of the ground are not possible in tun-

nels where the accumulated muck from each preceding blast must be partially removed and the roof trimmed before the columns can be set up. Before firing, drills, tripods, bench hose, and scaffolding must be removed to a safe distance, which requires considerable time.

1529. Average Progress in Driving.—Eight sections of the New York aqueduct tunnel gave an average monthly progress of 127 feet for full section of about 16 × 16 feet. The average weekly progress in best ten headings, using Ingersoll drills, was 38.73 feet, an average of 6.45 feet per day. Average monthly progress made by Ingersoll drills at Vosburg tunnel on the Lehigh Valley Railroad was 202 feet, the tunnel section being about 24 × 26 feet. By hand drills the average monthly progress at the two ends of the same tunnel was 61 and 73 feet, respectively. Material was a hard gray sandstone. A monthly average of 150 feet for a full tunnel section is first-class work. The day is divided into two shifts of ten hours each. There is an hour's interval for changing shifts, and a dinner hour at 12 o'clock noon and 12 o'clock midnight.

1530. Lighting.—In modern tunnel work electric lights are almost exclusively used. Oil lamps are to be condemned, as they pollute the air. Tallow candles may be used instead.

1531. Trackwork in Tunnels.—In laying the permanent track, only first-class material is admissible. As the roadbed is free from the action of frost, the track, after two or three thorough surfacings, should require comparatively little attention, except that given by the track walker. Rock ballast is invariably used. Ditches should be large enough to secure complete drainage. Oak ties are to be preferred, of uniform dimensions, and spaced 18 inches center to center of tie. Tunnel ties should be of the following dimensions: Length, 8 feet; breadth, 8 inches; thickness, 7 inches. There should be at least 8 inches of rock ballast between bottom of tie and tunnel floor, giving a total thickness of

ballast of 15 inches. When the tunnel lining has an invert, i. e., when the section of the floor is concave, the drain is sometimes built under the track, and covered with flags to prevent clogging with ballast. Side ditches are to be preferred, as they are always accessible and easily cleared.

PROTECTION WORK.

1532. Classification.—Under this head will be considered *surface ditches, changing channels of streams, crib work, paving, etc.*

1533. Surface Ditches.—Surface ditches are cut at the top of slopes, but at sufficient distance from them to prevent the water from breaking through and washing down the slope. Where the natural slope of the ground is towards the center line and of such a degree that a large proportion of storm water runs off, the surface ditches should be cut before construction commences. When this important precaution is neglected, it often occurs that a great amount of storm water is discharged into open cuts, effectually stopping all work until the water is drained off

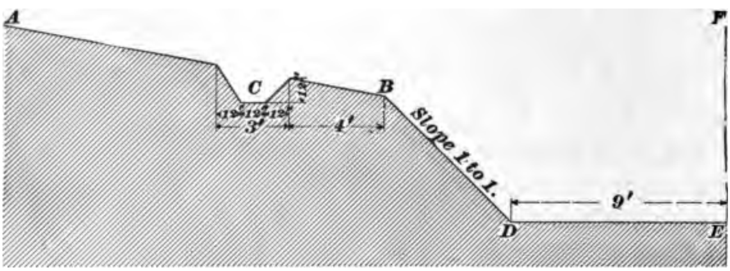


FIG. 455.

and the ground becomes dry enough to handle. The sight of men and animals floundering in flooded cuttings is too common in railroad work. Many contractors, and especially sub-contractors, are of limited experience, financially irresponsible, and generally follow a penny-wise policy. In such cases, the engineer in charge must insist on such precau-

tions being taken as will insure a vigorous prosecution of the work. Ditches are usually paid for at the same price per cubic yard as ordinary excavation.

Fig. 455 shows a section of a surface ditch which will meet the requirements of most situations. The line *A B* represents the natural slope of the ground; *C*, the surface ditch; *B D*, the side slope of the cutting, and *D E*, the half width of the roadway. The center line of the road is denoted by *E F*.

1534. Changing Channels of Streams.—It frequently happens when the line of road is parallel to the general direction of a stream that the windings of the stream repeatedly cross the line of the road.

By changing the channel of the stream at favorable points, a great saving is made in the cost of construction. A situa-

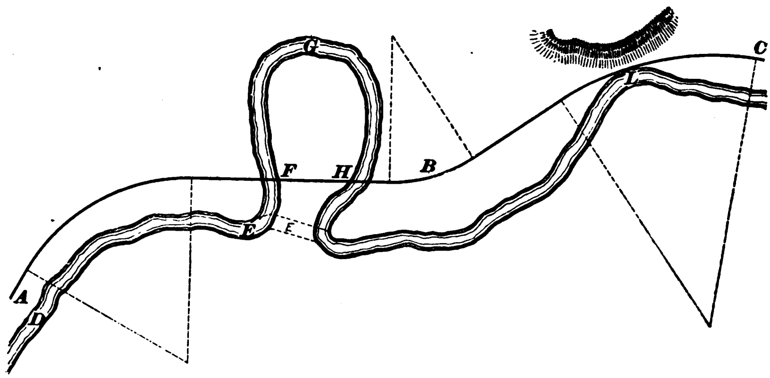


FIG. 456.

tion which warrants the changing of a channel is shown in Fig. 456, in which the located line *A B C* crosses the stream *D G L* at *F* and *H*, requiring an expensive bridge at each point. By cutting a channel across the narrow neck *E*, both bridges are avoided. Such instances are of frequent occurence.

1535. Crib Work.—When the foot of an embankment is subject to the erosion of a current of water, as at *L* in Fig. 456, a crib work of logs and stones is built into the embank-

ment at the exposed point. Protection cribs are ordinarily built of round timber, so combined as to form compartments, which are filled with stone to give them stability and with-

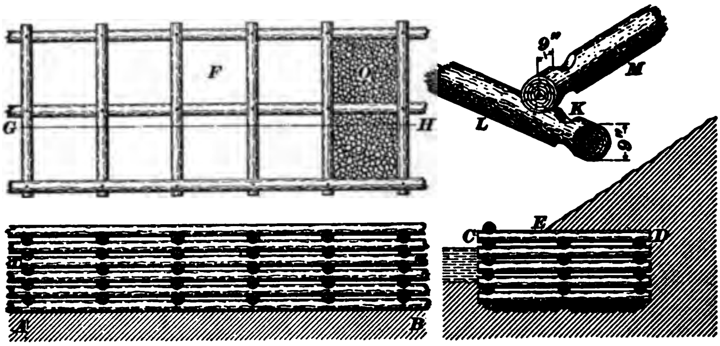


FIG. 457.

stand the action of the current. A general plan of the crib is given in Fig. 457.

Cribs serve the purpose both of retaining walls and of revetments. Their chief advantage lies in their adaption to situations where the cost of retaining wall foundations would be excessive. They can be readily built on wet, marshy soils or in swift running water. When weighted with stone, the structure sinks, and additional courses are added to the top until the required height is attained. The usual custom is to excavate a pit to a depth of from 12 to 18 inches, the bottom course of rangers, i. e., the logs running lengthwise in the crib, being laid close together. Where there is danger of scour from the current, the outside compartment is sometimes built with an open bottom. As the water works under the crib, the stone drops from the compartment above, forming a rip rap which prevents further action of the current. The lower courses of the crib, being kept constantly moist, are free from decay. The earth and sand from the sustained embankment are gradually washed into the cavities in the ballast until the whole forms one compact mass of great strength and solidity. In Fig. 457 *A B* is the front elevation, the line *A B* being parallel to the

direction of the current, *C D* shows a section of the crib, and *E* the foot of the embankment which slopes away at the natural slope of earth, viz., 1½ to 1. A plan of the crib is shown at *F* and the foot of the embankment by the broken line *G H*. A detail of a joint is shown at *K*. The log *L*, corresponding to *r s* in the elevation, is called a **ranger**; and the log *M*, corresponding to *C D* in the section, is called a **cross-tie** or **tie.** At each joint a drift bolt, usually a piece of ¾-inch round iron sharpened at one end, is driven to fasten the logs together. The bolt should be of sufficient length to pass through three logs. A hole of slightly less diameter than the bolt is bored to receive the bolt. A compartment filled with stone is shown at *O*.

1536. Paving.—Paving as applied to protection work consists of a stone covering laid on the surface of embankments where they are exposed to the action of water. The paving is usually 12 inches in depth and composed of good-

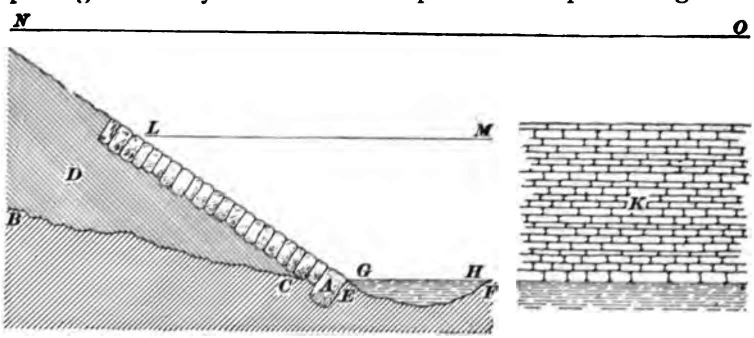


FIG. 458.

sized stone of fairly regular shape and even beds, the beds being laid perpendicular to the slope of the embankment, and when finished the whole to present a fairly uniform surface. The slope of the embankment should be smoothed and well rammed before the paving is laid.

A foundation course of heavy stones *A*, Fig. 458, is laid at the foot of the embankment in a pit from 12 to 18 inches in depth, depending upon the nature of the soil. When the stream has a rocky bed the foundation course is laid

upon the surface. The profile of the surface of the ground is shown by the irregular line *B C*; the earth embankment by *D*: the bed of the stream by *E F*; the surface of low water by *G H*, and of high water by *L M*. The elevation of the protected surface is shown at *K*, with the joints of the stones well broken. The grade of the roadway is indicated by the line *N O*.

ROUTINE WORK.

1537. Routine Work of the Engineer Corps.—The initial work of the construction corps, viz., the checking and betterment of the alinement, the referencing of transit points and cross-sectioning, together with the location and conduct of tunnel work, have already been described. The *routine work* which occupies the engineers' time from the commencement of the construction to its completion will be considered under one head.

1538. To Lay Out a Culvert at Right Angles to the Center Line, Which is a Tangent: The rule for laying out box culverts was given in Art. **1462.** The stakes for pit excavations and for neat lines of masonry are arranged as shown in Fig. 459.

The broken lines show the outlines of the foundation pit, which extends from six to twelve inches outside the neat lines of the masonry, depending upon the depth of the foundation. Ordinarily six inches is sufficient. The pit should be large enough to permit a thorough inspection of the masonry. The face lines of the masonry are located with the transit. The center line *X Y* of the culvert being at right angles to the center line *P Q* of the road, a plug is set at *K*, Fig. 459, at the intersection of the center line of the road and the center line of the culvert. The instrument is then set up at *K* and a right angle turned in the line *X Y* for locating face lines. The height of the embankment at this point is nine feet; the culvert opening two feet wide and two feet high; the covering flags are one foot thick, and the parapet one foot high. Then, according to the rule for find-

ing the dimensions of a box culvert, given in Art. **1462,** we have 9 feet − 4 feet = 5 feet; $1\frac{1}{2} \times 5$ feet = 7.5 feet; 7.5 feet + 1.5 feet = 9.0 feet; 9 feet + 8 feet, the half-width of the roadway = 17 feet, the distance from center line of road to the end of the culvert. We then measure on the line $X\,Y$ the distance $K\,L = 17$ feet, setting a plug at L. On the same line six or eight feet from L set a temporary point M. Then, set large stakes at A and C, twelve inches from M, in lines at right angles to $L\,M$, estimating the angles by the eye. Measure accurately the distances $M\,A$ and $M\,C$, each twelve inches, and drive a lath nail in both stakes, checking the distance $A\;C = 24$ inches. Then, reverse the instrument, setting a plug at N, 17 feet from K, and a point at O for locating the stakes at B and D, checking the measurements

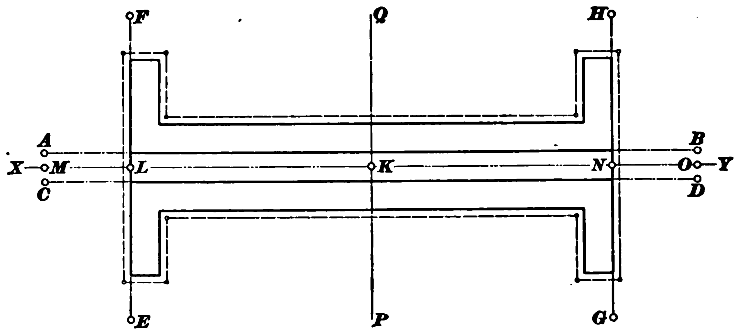


FIG. 459.

as at A and C. Next, set the instrument at N and turn the angle $K\,N\,H = 90°$. Applying the rule given in Art. **1462,** for finding the length of wing walls, we have 2 feet, the height of abutments + 1 foot, thickness of flags = 3 feet; $1\frac{1}{2} \times 3$ feet = 4.5 feet; 4.5 feet + 2 feet = 6.5 feet, the distance from the face of the opening to the end of wing wall. On the line $N\,H$ set a stake at H, ten or twelve feet from N, and drive a lath nail in the stake on line. Reverse the instrument, and at the same distance from N set a stake at G, with a tack on line. Next move the instrument to L, and turning a right angle to $X\;Y$, set stakes at E and F. With these stakes for a guide, the engineer can locate the pit

corners with the tape alone. A stake is driven at each corner of the pit, and after the excavation is made and the paving is laid, cord is stretched from the tacks in the stakes from A to B, C to D, E to F, and G to H, marking the face lines. All other needed lines the mason can lay out for himself.

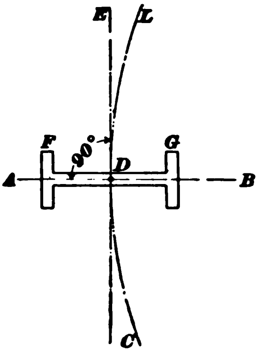


FIG. 460.

1539. When the Center Line of the Road is a Curve.—On curves, as on tangents, wherever possible, the center line of the culvert is placed at right angles to the center line C L on the road, i. e., at right angles to the tangent D E of the curve at the center D of the culvert (see Fig. 460). The wing walls F and G are parallel to this tangent. The dimensions of a culvert on a curve are the same as those on a straight line, with the same height of embankment.

1540. When the Center Line of the Culvert Makes an Oblique Angle with the Center Line of the Road, i. e., When the Culvert is Askew.—First find what the length of the culvert would be if it were at right angles to the center line of the road. This will give the base of a right-angled triangle, one of whose angles is the angle of skew. The other is easily found by subtracting the angle of skew from 90°. The hypotenuse will be the required side distance. The wing walls must, in all cases, be parallel to the center line of the road.

EXAMPLE.—A railroad embankment is 12 feet in height. A box culvert with opening 3 feet wide and 3 feet high must be built askew at an angle of 70° with the center line. What is the distance from the center line of the road to the center of the opening at the face of the culvert?

SOLUTION.—Let A B, Fig. 461, be the center line of the road, and C D the center line of the culvert, A K $C = 70°$ being the angle of skew. At K draw E F at right angles to A B. From the given dimensions of culvert and height of embankment, we have for a right-angled culvert, side distances as follows: $12 - 5 = 7$, $1\frac{1}{2} \times 7 = 10.5$, $10.5 + 1.5 = 12$,

$12 + 8 = 20$ feet, the side distance. Lay off on KE the distance $KG = 20$ feet. Draw GH perpendicular to KG, forming the right-angled triangle KGH, of which the angle $GKH = 20°$ and the side $KG =$

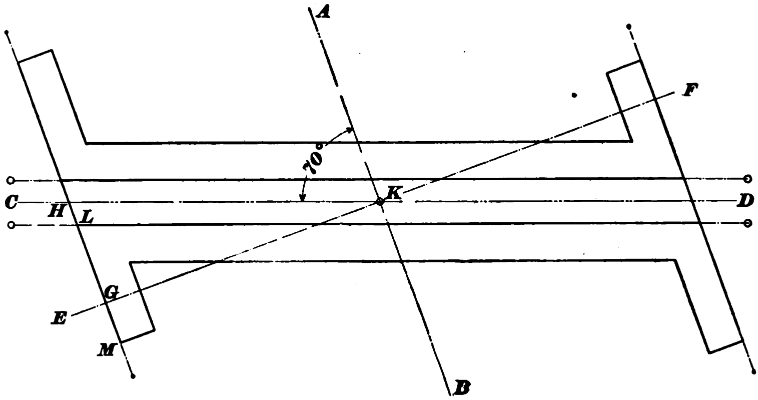


FIG. 461.

20 feet. The side length, which is the hypotenuse KH, is found by the formula $\cos 20° = \frac{GK = 20 \text{ feet}}{\text{hypotenuse } KH}$, or hypotenuse $KH = \frac{20}{\cos 20°} = \frac{20}{.93969} = 21.28$ feet = the side distance. Ans.

The wing walls for a right-angled culvert of the given dimensions would have a length of $1\frac{1}{2} \times 4 = 6$; $6 + 2 = 8$ feet. Their length LM for the given culvert is found by the following proportion:

$$20 \text{ ft.} : 21.28 \text{ ft.} :: 8 \text{ ft.} : LM,$$

whence the length of skewed wing wall $LM = \frac{21.28 \times 8}{20} = 8.51$ feet.

Side and wing walls are $2\frac{1}{2}$ feet thick and covering stones 1 foot thick. The dimensions of the foundation pit are proportionately the same as in Fig. 459. The stakes for the neat lines of the masonry are located as in that figure.

Skewed culverts are of greater length and contain more material than those at right angles to center line of road, and, when arched, they are much more costly to build. Considerable expense may, therefore, be properly incurred in altering a channel so as to obtain a right-angled crossing.

1541. Borrow Pits.—Borrow pits are excavations made for the purpose of obtaining additional material for embankments when the regular excavation does not furnish an adequate supply. The simplest form of borrow pit is a trench dug parallel to the center line, a space of suitable width being left between the slope stakes and the edge of the pit. This space, or **berme,** as it is called, should be six feet in width. Formerly, much of the material taken from such borrow pits was handled with wheelbarrows. In modern practice, where the material admits of it, the wheeled scraper is invariably used. The amount of material needed for the embankment in excess of that furnished by the adjacent cuts is readily calculated. This excess is first excavated from side borrow pits and deposited in place, after which the material from the adjacent cuttings is added.

Another means of borrowing material, and one which is always adopted where the haul is not too great, is by widening the cuts. In proportion as the cut is widened, the danger of the ditches being filled up by caving embankments or snow is removed.

Where embankment is made from material *cast* from the sides of the road, the berme is rarely more than four feet in width. When the building of a road is only possible through the exercise of the greatest economy, a berme of four feet is admissible, even though it may involve increased expense at some future time. Side work of this kind has been let on some of the cheap Dakota lines at a price as low as 12 cents per cubic yard, with an average height of embankment of 2 feet. These lines were built through an unsettled country, and carried the settlers who were to furnish the future business for the road. As the country settled up and traffic increased, these roads were practically rebuilt. The original grade lines, whenever practicable, followed the undulations of the prairie. In rebuilding, these grades were greatly improved by filling up the sags. On many sections the amount of material added was double that put in the original work.

1542. Calculating the Contents of Borrow Pits.—Where the entire embankment is made from side borrow pits, the contents of the embankment with an allowance for shrinkage is taken as the contents of the pits. This process of measurement saves work and is more accurate than measuring the dimensions of the several pits, especially when they are made with wheeled scrapers which leave the pits in irregular shape.

When the cuts are widened for borrowed material, the surface cross-sections are extended far enough to include the additional excavation. After the work is completed, the cross-sections are again taken. Both cross-sections are platted on the same sheet, which, at once, shows the amount of the excavation.

Frequently the embankment is many times greater in volume than the tributary cuttings, involving an extended borrow pit. In such cases the cross-sections sometimes extend several hundred feet from the center line. Fig. 462 shows a borrow pit of this character with the usual form of cross-section.

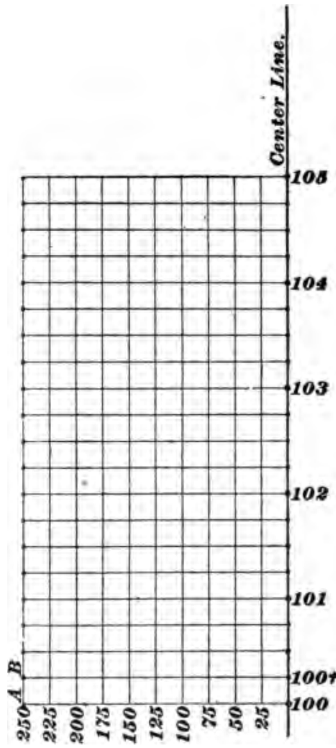


FIG. 462.

In this figure the proposed borrow pit is situated on the left of the center line, and the cross-sections include an area extending in length from station *100* to station *105*, and in width 250 feet from the center line. A bench mark is established at a convenient distance from the borrow pit, to be used in taking cross-sections for monthly

estimates and final cross-sections. The surface levels are taken as follows: Stakes are driven on the center line 25 feet apart, commencing at station *100*, and an equal number at corresponding points on a line 250 feet from and parallel to the center line. A rope 250 feet in length, with tags tied at intervals of 25 feet, is stretched from station *100* to the stake at A, 250 feet distant. A rod reading is then taken at each 25-foot tag and recorded. The line is then moved forward 25 feet, one end being held at station *100 + 25*, and the other at B, and the levels on this line taken. In the same way the entire surface is covered. This arrangement divides the surface into squares of 25 feet on a side. For monthly and final estimates the cross-sections are taken at the same points, which insures accuracy and greatly simplifies calculation.

The surface sections are platted on cross-section paper, and placed far enough apart on the sheet to avoid overlapping when the monthly and final sections are platted. The cross-sections for each monthly estimate are platted in a different color, excepting the surface and final sections, which are in black. Cross-section books, the leaves of which are ruled like standard cross-section paper, are very convenient for platting sections of borrow pits and special excavations. They may be used in the field, like ordinary note-books, the notes being recorded in pencil, and *inked in* at the office when leisure time permits. For platting work of this kind, cross-section books are far preferable to *loose sheets*, which are sure to become soiled from repeated use, and, in spite of the greatest care, some are lost.

1543. Checking the Center Line.—During construction, and especially on embankments, the center line should be frequently checked, i. e., run in on the incompleted embankment. All materials will not at once take the natural slope of 1½ horizontal to 1 vertical. Frequently the embankment becomes one-sided, and a line of centers reveals at once any irregularity. Contractors often sustain

a loss on account of material being wasted. It is the duty of the engineer to restore centers whenever they are needed, whether asked for or not.

1544. Grade Stakes.—When the roadway, either in cutting or on embankment, is brought approximately to grade, a grade stake is set at intervals of 100 feet. On embankments the stake is driven on the center line, with its top at grade. In cuttings the stake is driven at the side of the roadway, and a peg is driven near the foot of the stake. The elevation of the top of the peg is taken, and the amount of cutting which must be made below the top of the peg to reach the grade line is written upon the stake.

1545. Care of Stakes.—The destruction of stakes by contractors' workmen, and the disregard of them by contractors themselves and their foremen, is about universal. There is no regularly prescribed penalty for such criminal carelessness. The cost of restoring stakes should be charged to the contractor at double price. A literal enforcement of specifications in minor details, where they might be relaxed to the advantage of the contractor and with no detriment to the railroad company, has caused many a contractor to regret his carelessness in this matter. A trick of dishonest contractors is to move slope stakes nearer to the center line, and so reduce the quantity of excavation or of embankment. An alert engineer will soon get the true measure of the contractors under him, and detect deceit of this kind.

1546. Provision for Settling.—Embankments are raised from 5 to 10 per cent. above the established grade to provide for the shrinkage which invariably takes place in all earth embankments. The amount of this percentage is fixed by the engineer in charge, and depends upon the nature of the material composing the embankment. Compact clay or gravel will not settle or shrink more than half as much as soft alluvial soils.

1547. Overhaul.—Many contracts for railroad work specify the maximum distance to which material shall be transported at the given price per yard. When the distance exceeds that specified in the contract, the excess is termed *overhaul*, and a clause in the contract stipulates what additional compensation shall be made for each hundred feet of overhaul. *Free haul* is commonly limited to 1,000 feet, and for each hundred feet of *overhaul* an addition of 1 cent per cubic yard is made to the contract price per yard. In recent years the overhaul clause is omitted from most contracts, as it is almost sure to involve litigation.

BRIDGE WORK.

1548. The Location of Bridges.—There are two important factors in the location of a bridge, viz., first, the determination of the angle which the center line of the road shall make with the general direction of the channel, and, second, the measurement of the span.

In all cases it is desirable that there should be a right-angled crossing, and for bridges of large span the alinement is often modified to obtain that result. The amount of such modification, if any, will depend upon the importance and character of the traffic. If the line is for through business where numerous passenger trains are to be run at high speed, the angle of the crossing will be subservient to the alinement; that is, a skewed bridge will be adopted rather than to introduce curvature and mar the directness of the line.

Skewed bridges are always more expensive and generally less satisfactory than those crossing streams at right angles.

The character of the crossing being determined upon, the next thing in order is the measurement of the span. This may be effected in two ways, and, when practicable, both methods should be used, the one serving as a check upon the other. The first method is by direct measurement; the second by triangulation. Before either method is applied, the center line must be accurately checked and

established by fixed monuments set on both sides of the stream.

1549. Direct Measurement of Span.—The direct measurement of the span is made as follows: A light strong steel wire is stretched from monument to monument, spanning the stream. One end of the wire is fixed so that the wire is either in actual contact with the point in the monument or directly over it. To the other end a spring balance is attached, which indicates by a dial the amount of tension placed upon the wire.

The wire is then stretched until the sag is practically removed, and the amount of tension noted. If the wire is not in direct contact with the monument centers, the measurement is found by plumbing from the wire to the monuments. The points of measurement are then marked on the wire and the measurement repeated. The measurement should be made at least three times, the wire being subjected to the same tension. As one end of the wire is fixed, any variations in measurement will show at the free end. If the measurements show any considerable variation, the process must be repeated until *three* measurements practically agree. Two supports are then erected upon a level surface, at a distance from each other equal to the span of the stream, and of such height that the wire *will clear the ground* when stretched between the supports at the same tension as used in the original measurement. The wire is then stretched with the proper tension, and the points of measurement transferred to the ground by plumbing. The measurement on the ground is made with a standard steel tape, and repeated three times. The average of the three measurements, providing their discrepancy is slight, may be accepted as the correct measurement of the span.

1550. Measurement of the Span by Triangulation.—If practicable, the same monuments used in direct measurement are used in triangulating. The first step is the establishing of a *base line*, which should be of approximately the *same length* as the *span*, and laid out on as smooth

ground as the situation will permit. The measurement of the base line is made with the greatest care and repeatedly checked. When the ground is practically level the following method is recommended (see Fig. 463): Strong stakes are driven at A, B, C, etc., approximately 100 feet apart, their tops being on the same level and pointed, with a small tack in each stake. The spaces between the stakes are then measured with a steel tape at a tension of about 15 pounds.

The measurements are made three times, and the average of them taken as correct. Greater accuracy in measurement is secured by having different persons read the tape for each measurement, each recording his own reading, and after the third reading place the three readings in a column

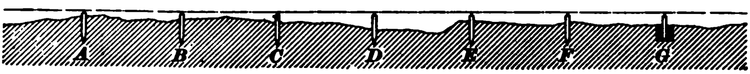


FIG. 463.

and take the average for the correct measurement. The sum of the averaged measurements will be the length of the base line A G. Suppose for this case that they are as follows:

$$\begin{array}{r} 99.892 \\ 99.997 \\ 99.8963 \\ 99.957 \\ 99.9466 \\ 99.880 \\ \hline 599.5689 \text{ feet,} \end{array}$$

which gives for the total length of the *base line* 599.5689 feet.

Let Fig. 464 be the plan of the bridge crossing. A and G are monuments in the center line on each side of the river, and B G the *base line*, whose length we have determined by direct measurement to be 599.5689 feet. The angles at A, B, and G are measured three times, and the average of the readings taken as the correct reading. It is desirable to use a transit which will read to 10 seconds. On

bridges of great length the angle readings are taken in three sets of five readings each, and the average of all accepted as the correct reading. This mode of angle measurement was adopted in measuring the span of the Washington bridge over the Harlem river, at New York. Suppose that the average of three readings makes the angle at A, 57° 29′ 35″; at B, 59° 01′ 03.3″ and at G, 63° 29′ 20″. Their sum is equal to 179° 59′ 58.3″, which proves the angle meas-

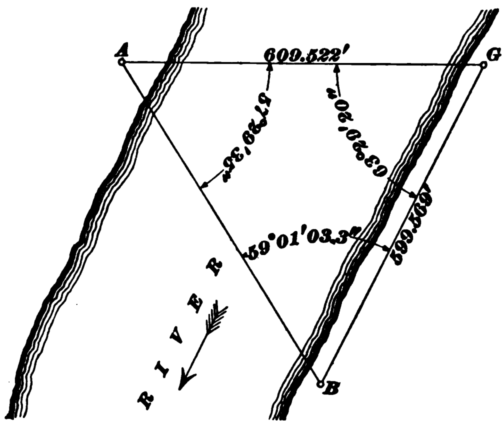


FIG. 464.

urement to be practically correct. The length of the side $A\ G$, i. e., the span, is determined by the principles of trigonometry (see Art. **1243**), as follows:

$$\text{Sin } 57°\ 29'\ 35'' : \sin 59°\ 01'\ 03.3'' :: 599.569 : \text{side } A\ G.$$

$$\sin 59°\ 01'\ 03.3'' = .85733$$
$$599.569 \times .85733 = 514.028491$$
$$\sin 57°\ 29'\ 35'' = .84333$$
$$\frac{514.028491}{.84333} = 609.522 \text{ ft.} = \text{side } A\ G.$$

If the temperature of the air in this case were 60° Fahrenheit, it may be considered normal, so that there need be no allowance made for the expansion or contraction of the tape. The base line $B\ G$ is practically parallel to the direction

of the channel current as indicated by the arrow, and the angle at *G* of 63° 29′ 20″ will be the angle of skew to which the bridge will be built.

1551. The Location of Piers and Abutments.—The number of piers to be built will depend upon whether the stream is navigable or not, and upon the cost of foundations. If the stream is navigable there must be one channel span of such width as the Government authorities shall determine.

When no provision is required for navigation, the cost of foundations alone will determine the number of piers. In general, the cost of bridges will increase about as the square of the span; that is, if *one* bridge is of *twice* the span of another, the first will cost about *four times* as much as the second. If the stream is shallow and its bed of rock or compact gravel or clay, suitable for foundations, it will be cheaper to increase the number of piers, and shorten the spans proportionately.

1552. Foundations.—This subject is too broad for any but general treatment. A bridge foundation must meet two conditions, viz., stability and security; that is, it must be able to safely support the maximum load imposed upon it, and must be protected against those natural forces which either periodically or continually attack it. The principal enemies of bridge foundations are the erosive action of the current and floating ice, both of which are most active at high stages of water. Bridge piers, with few exceptions, are of stone. Pier foundations may be divided into three classes, viz., *rock* or *concrete* foundations, *pile* foundations, and *caisson* foundations.

1553. Rock and Concrete Foundations.—When the bed of the stream is rock or compact gravel, sand, or clay, the pier site is prepared as follows: When of rock, trenches equal in width to the thickness of the outside walls of the pier are excavated to a depth of 12 inches. The bottom of the trench is brought to the same general level,

and a layer of concrete added to furnish an even bed for the masonry. As foundations are generally built at low stage of water, the action of the current is but slight.

When compact sand or hard clay forms the bed of the stream, a dam is built enclosing the foundation site. If the water is stagnant and of a depth not exceeding 4 feet, a trench is dug from 12 to 24 inches in depth, enclosing the foundation, and the trench is then filled with clay and gravel, well mixed and thoroughly rammed, forming a wall which is carried above the surface of the water. The enclosed water is then pumped out and the foundation area excavated to a depth of from 12 to 24 inches, depending upon the erosive force of the current and the weight of the proposed pier. The pit is then filled with well-rammed hydraulic concrete, and the masonry laid precisely as on shore. The two lower courses of masonry are stepped outwards, that is, they project beyond the main body of the pier, increasing the bearing surface of the foundation. These footings or offsets are made from 4 to 6 inches wide. The foundation courses should be of larger stones than those composing the main body of the pier. The faces of the pier are usually battered from $\frac{1}{2}$ to 1 inch horizontal to 1 foot vertical. Where the piers must resist heavy masses of floating ice, the up stream ends are brought to an edge, forming ice breakers.

1554. Cofferdams.—For depths of stagnant water greater than four feet and for less depths having a current, the clay dam is replaced by a cofferdam. This construction consists of two rows of piles which are driven enclosing the foundation site. The distance apart of these rows of piles, as well as the spacing of the piles in the rows, will depend upon the depth of the water surrounding the foundation site, and the nature of the material into which the piles are to be driven. The piles will also be required to support a platform, upon which are placed the derricks, hoisting machinery, and building material used during construction.

The usual form of construction of a cofferdam is shown in Fig. 465. Two rows of piles *P*, *P* are firmly driven, enclosing the foundation area. Longitudinal pieces of squared timber *W*, *W* called **string pieces** or **wales** are bolted to the piles a little above the water level. Directly opposite the string pieces on the inside of the piles, **guide pieces** *g*, *g* are bolted, the same bolt passing through both string piece and guide. The guide pieces serve to keep the sheet piles *S*, *S* in line while being driven. Cross timbers *B*, *B* called **binders** are notched down on the string pieces to which they are bolted. The depositing and ramming of the puddle tend to cause the rows of piles to spread.

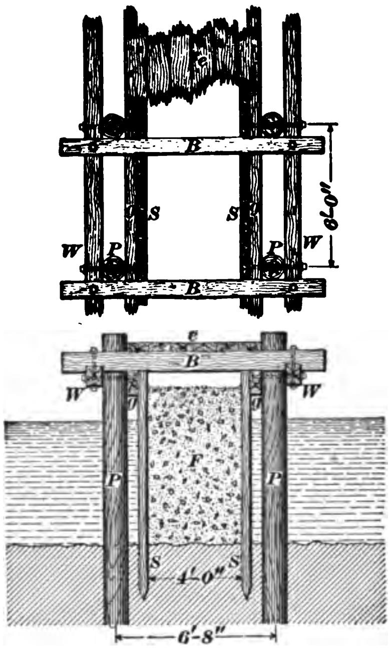


FIG. 465

The binders prevent this and give strength and stability to the structure. The plank flooring *e* supports the derricks, hoisting machinery, building material, etc. The consistency of the cofferdam filling must be such as to exclude the water, and the weight and strength of the entire structure must be sufficient to resist the pressure of the excluded water. Taking the weight of water at 62½ pounds per cubic foot, the external pressure of the water against the sides of a cofferdam is determined by the following rule (see Art. **975**, Vol. I.):

Rule.—*The pressure upon any vertical surface due to the weight of the liquid is equal to the weight of a prism of the liquid whose base has the same area as the vertical surface,*

and whose altitude is the depth of the center of gravity of the vertical surface below the level of the liquid.

Cofferdams are really retaining walls, which were fully described in Arts. **1486** to **1490,** inclusive, and the forces acting against them are the same, though somewhat different in application. In the case of retaining walls, the *backing* being of earth or broken rock, only that part of the backing included between the back of the wall and the line of natural slope, extending from the inner foot of the wall upward at a slope of $1\frac{1}{2}$ horizontal to 1 vertical, exerts any pressure upon the wall. In the case of water, however, the particles, having no cohesive force, all exert pressure against the dam. The center of pressure of the water, like the center of pressure of the forces acting against a retaining wall with backing level with its top, is taken at one-third of the depth of the water above the bottom. The direction of the water pressure is at right angles to the face of the cofferdam, and the moment of the water pressure is the product of the pressure found by the above rule multiplied by one-third the depth of the water. The moment of the resistance of the cofferdam, that is, its *stability*, or *resistance to overturning*, is the product of its weight multiplied by the distance from the inner toe of the cofferdam to the vertical line drawn from the center of gravity of the cofferdam.

EXAMPLE.—If, in Fig. 465, the length of a cofferdam is 50 feet, its height 7 feet, its thickness 4 feet, and the depth of water 6 feet, (*a*) what is the pressure of the water against the side of the cofferdam? (*b*) What is the overturning moment of the water pressure, and the resisting moment of the dam? (*c*) What is the factor of safety of the dam?

SOLUTION.—(*a*) $6 \times 50 \times 3 \times 62.5 = 56{,}250$ lb., the pressure against the side of the cofferdam. Ans.

(*b*) In determining the moments of the water pressure and of the resistance of the dam, we take a section of the dam 1 foot in length. The pressure of the water against a 1-foot section of the cofferdam is $6 \times 3 \times 62.5 = 1{,}125$ lb. Its center of pressure is at one-third the depth, or 2 feet, above the bottom. The moment of the water pressure is, therefore, $1{,}125 \times 2 = 2{,}250$ lb. Ans.

Taking the weight of the puddle filling at 120 pounds per cubic foot,

we have for the weight of a 1-foot section $7 \times 4 \times 120 = 3{,}360$ lb. The moment of resistance of the dam is the product of its weight by the perpendicular distance from the inside toe of the dam to the vertical line from the center of gravity of the section. This perpendicular distance is 2 feet. $3{,}360 \times 2 = 6{,}720$ lb. Ans.

(*c*) This moment opposes the moment of the water pressure, which we found to be 2,250 lb. The factor of safety of the dam is, therefore, the quotient of $6{,}720 \div 2{,}250 = 2.99$, nearly. Ans.

In this calculation we have ignored the weight of the piles and timber composing the cofferdam, as well as the resisting power of the piles. These would considerably increase the factor of safety of the dam. The water pressure per square foot upon the bottom of the enclosed area will be equal to the depth of the water (6 feet) multiplied by 62.5, or $6 \times 62.5 = 375$ pounds. This pressure is resisted by the material composing the bed of the stream and the sheet piling.

If the bed of the river is composed of compact sand or clay, little trouble need be anticipated. If, however, the bed consists of loose sand and gravel, special provision must be made to exclude the water.

An effective device used by French engineers is the following (see Fig. 466): Two rows of piles *P*, *P* are firmly driven. Wales *W*, *W* and guides *G*, *G* are bolted to the piles. A row of close piles *C* of square timber is driven and bolted or pinned to the outside guide. The foundation area and the space to be covered by the cofferdam filling are dredged to the depth of 3 or 4 feet and the entire pit filled with concrete. Before the concrete has had time to set, the inside row *D* of close piles is driven, their feet penetrating 2 feet into the concrete. The clay filling is deposited to the depth of one foot upon the fresh concrete and rammed, so there may be a perfect connection between the puddle and the concrete. This work must be done with dispatch. The remainder may be deposited more gradually. After sufficient time has elapsed to allow the bed of concrete to become thoroughly hardened, the water is pumped out of the enclosure. If the pressure of the water is great enough

to lift the concrete foundation, additional weight must be added to keep it secure until the weight of masonry insures stability.

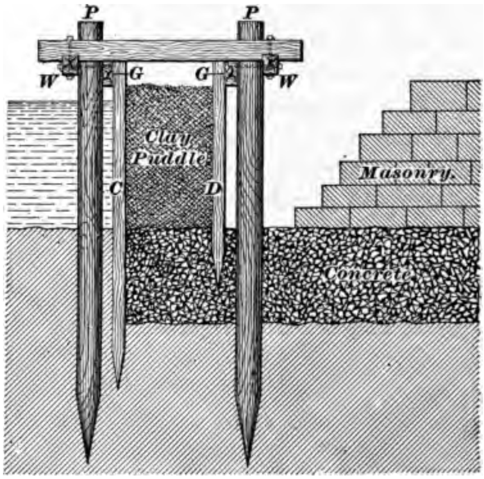


FIG. 466.

1555. Pile Foundations.—When the river bed is composed of soft, yielding alluvium extending to a considerable depth, but underlaid by a firm soil of ample depth, a pile foundation is commonly adopted. The piles should not exceed in length thirty times their butt diameter, and should be cut from live straight trees. Oak piles are the most durable and strongest; rock élm, spruce, and yellow pine are of about equal strength and durability. The outline of the proposed pier will to some measure determine the arrangement of the piles, but the general arrangement is always the same, and is as follows: The piles are driven in rows, spaced not less than two and a half feet, center to center, and cover the entire foundation area.

In some special cases the outside row of piles is made double, the outer piles projecting beyond the outlines of the pier. The calculation of the bearing power of piles and the various methods of driving are fully explained in succeeding pages. The piles, after being thoroughly driven, are sawed

off at a uniform level at a suitable depth below *low water level*.

A general plan of the pile foundation and the masonry usually adopted for bridge piers is shown in Fig. 467. The dimensions of the foundation from center to center of outside piles are width 9 feet and length 33 feet, the pier being for a standard double-track roadway. The piles are cut off 4 feet below low water. A timber platform, or **grillage,** of heavy timbers is built upon the piles, to receive the foundation. First, a course of cap timbers is laid crosswise upon the heads of the piles. The caps are commonly 12 by 14 inches, and notched down 2 inches upon the pile heads, leaving 12 by 12 inches of solid timber above the piles. The caps extend six inches outside the piles, to which they are fastened with 1 inch square drift bolts. Care must be taken that the tops of the caps are on a uniform level. The second course of timbers is stringers 12 by 14 inches laid lengthwise of the pier, and notched down 2 inches on the caps to which they are drift-bolted at each intersection. They are laid close together, forming a complete flooring. A third course of 12 by 12-inch timbers is laid at right angles to the stringers to which they are securely drift-bolted. The top of the grillage should be at least 1 foot below low water. Upon it the masonry is started.

In Fig. 467 *A* shows the side elevation of the foundation and pier; *B*, the elevation of the up-stream end of the foundation and pier; *C*, the arrangement of piles in the foundation, and *D*, the plan of the pier. The courses *g* and *h* are the coping courses, the latter forming the seat upon which the bridge rests. The foundation piles are spaced 3 feet center to center. The grillage of timber extends on all sides 12 inches from the centers of the outside row of piles. The first course of masonry is laid flush with the outside of the grillage, and extends on all sides 6 inches beyond the second course. The second course projects on all sides 6 inches beyond the main body of the pier.

Beginning with the third course, the north end of the pier gradually develops into a conical-shaped ice breaker,

and in construction consists of the intersection of a cone with a wedge. The curve of intersection is shown in the

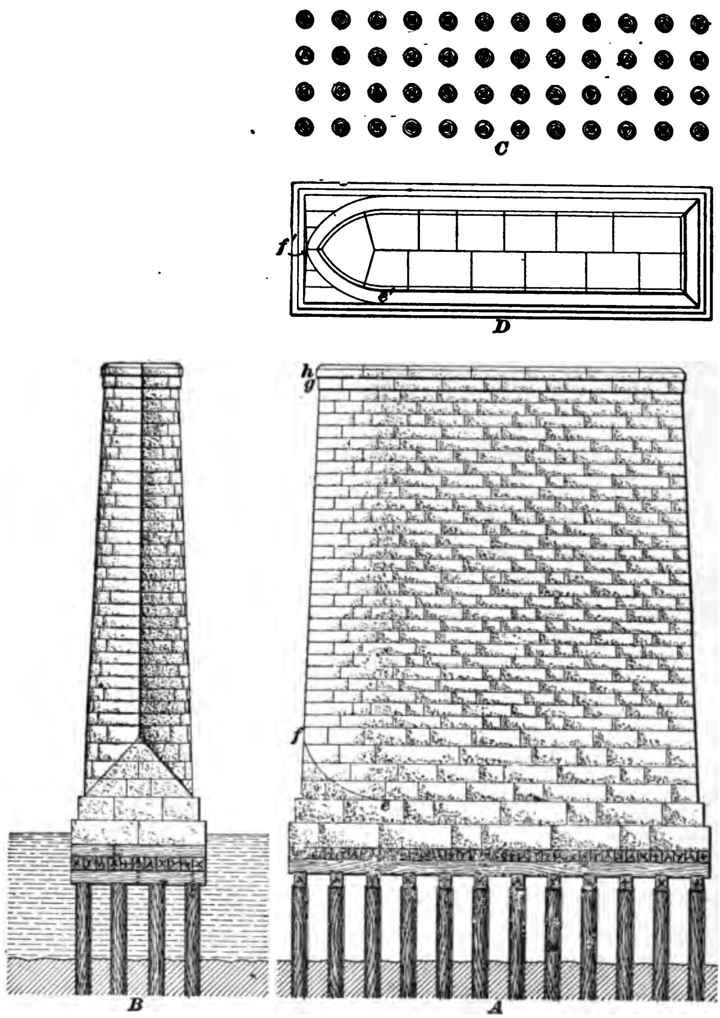


FIG. 467.

elevation by the curve $c\ f$, and in the plan by the curve $c'\ f'$. The arrangement of the stone in each course is shown in the

elevation *A*. It will be observed that in no instance is the bond less than 12 inches, and the proportion of headers (stones showing their short side at the face of the pier) to stretchers (stones showing their long side at the face of the pier), and their arrangement is such as to form one compact mass of masonry.

Where there is a rapid current, causing frequent changes of channel, as is the case with many Western and Southern rivers, it may be necessary to rip-rap the foundation. This process consists of depositing stone about the piles to a depth of 4 or 5 feet, the deposit extending several feet beyond the piles in all directions. Any action of the current tending to undermine the foundation is promptly checked by the rip-rap, which fills any cavity worn out by the current.

In making working drawings for bridge piers, the arrangement of the stones in each course should be carefully planned before the masonry is started. If only two or three courses are planned beforehand, confusion is sure to follow. By furnishing quarrymen with complete plans, they have a wider range of sizes, and will be enabled to take better advantage of the stone as it comes from the quarry. The probable result will be better prices and prompter delivery than when only partial plans are furnished.

In giving dimensions to quarrymen, no allowance is made for mortar joints, which in bridge masonry are usually one-half inch in thickness. When the given dimension is taken from an angle to the middle of a joint, the stone cutter will deduct one-fourth inch from the dimension for the neat length of the stone. When the dimension is from center of joint to center of joint, the stone cutter deducts one-half inch. Detailed plans are usually sent to the quarry where the stone is cut to dimension, and the several stones for each course numbered, the courses being designated as Course A, Course B, etc., or in some other way. The quarry foreman lays out the work, deducting the allowance for joints, and the stone is cut, marked, and shipped to the bridge site in shape for laying. Stones of irregular and intricate form

are drawn to a large scale of from 1½ to 3 inches to the foot, and often full-sized drawings are made, from which templates of sheet zinc are cut for use in the quarry.

1556. Stone Suitable for Bridge Masonry.—Stone for bridge foundations and piers must be free from seams and defects common to surface stone. Stones containing free iron are objectionable, as they are sure to become discolored from the action of the elements. Granite is to be preferred, but limestone, hard sandstone, bluestone, and marble are all suitable. In ordinary bridge work, the stone is laid rock face, i. e., with undressed faces, and pitched to line at the joints. By giving the corner stones a draft of two inches, i. e., so as to show two inches of dressed surface on each side of the angle, an effect of much higher finish is imparted to the entire work at comparatively small additional cost.

In cutting the stone, great care should be taken to make the beds even and the stone of uniform thickness throughout, so that when laid the beds will be truly horizontal. In coursed masonry all the stones in each course have the same thickness throughout. A variation of ¼ inch in the thickness of the stones is readily detected, even by an unpractised eye. All mortar used in bridge building should be prepared under the direction of a competent inspector, and under no circumstances used after setting has commenced.

1557. Backing.—The space inclosed by the face stone is usually filled with a less expensive material, called **backing.** In large piers, concrete is much used. It forms a homogeneous mass, and when well rammed, as it always should be, fills all the space between the faces. Rubble masonry is largely used for backing, and in laying, care must be taken to secure proper bond, especially between the backing and the headers which reach from the face into the body of the pier. Piers erected on caisson foundations are, on account of the great cost of sinking, given as small dimensions as are consistent with safety. To give increased weight and strength to the pier, the backing is cut to

dimension, so that, when laid, the masonry of each course, with the exception of the joints, forms one solid mass of stone.

1558. Coping.—The top course of masonry forms the coping and should project 2 or 3 inches over the main body of the pier. When the coping is of two courses, the projection is divided between them, and the outer edge of the top course is beveled to an amount equal to the total projection. The coping courses are usually dressed stone, which adds greatly to the finish of the work.

1559. Pneumatic Caisson Foundations.—River beds of alluvium extending to great depth, exposed to the scour of a constantly shifting channel, are not suited to pile foundations. The Mississippi and Missouri rivers are striking examples of this class. A firm bearing stratum of sufficient thickness to support a foundation is often from 80 to 100 feet below the bed of the river. To meet these conditions, caissons built of heavy timbers are sunk either to bed rock or to a firm stratum of clay or gravel of such depth as to insure permanent safety.

1560. Test Holes.—After the bridge site has been determined upon and before the bridge plan has been considered in detail, test holes are sunk on the center line at intervals of from 100 to 200 feet, to determine the character of the material forming the river bed. The results of these examinations will largely determine the lengths of the spans. The deeper the foundations the greater will be the spans. Having determined the locations of piers, test holes are sunk at each pier site, in sufficient number to afford ample knowledge of the character of the material to be encountered in sinking the caisson. A complete record of each test hole is kept, and a sectional profile platted, showing the specification.

1561. Modes of Sinking Test Holes.—Test holes are sunk either by diamond drills or by driving wrought-iron pipe. Piles are driven to support a platform, upon

which is placed the machinery used in sinking test holes. Wrought-iron pipe is commonly adopted. It is cut in sections of from 6 to 10 feet. The thread on pipe and couplings should be so cut that when coupled the ends of pipe will abut and so prevent the stripping of thread which is liable to result from the repeated blows of the driver. A steel cap, shown in Fig. 468, is screwed to the top of the pipe to receive the blows of the hammer.

1562. The Driver.—The driver is constructed on the principle of the pile driver. The hammer consists of a section of an oak or other hard wood tree, from 9 to 12 inches in diameter, turned to a uniform size and fitted at the sides with steel grooves, through which pass the guides extending the full length of the leaders. An iron ring is fastened in the top of the hammer to which is attached the rope used in raising the hammer. This rope passes through a common pulley with wooden sheave, which is fastened with rope to the head of the leaders.

The leaders are of sufficient length to allow the hammer a drop of 4 feet after a new section has been attached. A force of 4 or 5 men is required for the efficient working of the machine. In sinking into the earth, the pipe cuts a section equal to the inside area of the pipe. At intervals of 6 or 8 feet in sinking, and before an additional section is attached, the pipe is cleared by a sand pump.

FIG. 468.

FIG. 469.

FIG. 470.

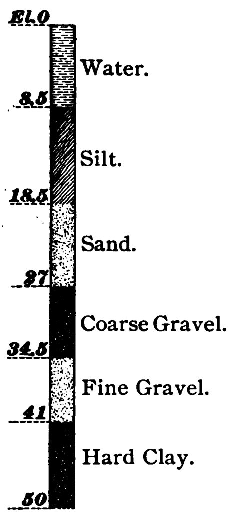


FIG. 471.

1563. The Sand Pump.—This pump consists of a section of iron pipe of such size as will work freely inside the pipe being driven. Fig. 469 shows longitudinal section and plan of sand pump. The valve *A* consists of a ball of iron which rests in a hollow seat and acts automatically. The pump is lowered into the pipe by means of a rope attached to the ball *B*. Water is poured into the pipe so that the contents may be reduced to a fluid state. As the descending pump strikes the surface of the water in the pipe, the valve *A* is forced upwards and the water and sand pass through the hole *C*. The upper part of the valve chamber *D* is ribbed, as shown at *E*. This arrangement confines the valve and at the same time allows the sand and water to pass into the chamber *F*. When small stones and pebbles enter the pipe and are too large to pass through the valve opening, they must be broken up by a churn drill. The best form of drill is one with a cutting edge or bit similar to that commonly used in steam drills, shown in Fig. 470.

The drill *A B* is about 18 inches in length. The cutting edge or bit *A* is in the form of a cross with equal arms. To the end *B* an ordinary pipe coupling is attached. The body of the drill is of gas pipe in sections, which are added as the hole deepens. The bit must be kept sharp and the couplings frequently examined that no stripping of thread occurs, which might easily result in the loss of the drill and prevent further sinking. Any change in the material removed from the pipe is readily detected, and the depth of the stratum is determined by measuring from the top of the pipe.

1564. Record of Test Holes.—A good form for keeping a record of test holes is given in Fig. 471, which shows a sectional profile, giving the thickness and character of each stratum passed through. The profile given in Fig. 471 is of a test hole driven in the bed of a river. After passing through different strata of sand and gravel, a stratum of hard clay is encountered. After penetrating 9 feet into this clay, any further sinking is unnecessary, since 9 feet of

hard clay will afford a foundation amply strong for any ordinary bridge.

1565. Dimensions of Caisson.—The depth of the foundation stratum will affect the size of the caisson as the faces of the pier are battered, increasing the size of the plan as the depth increases.

For example, suppose the neat dimensions of a bridge pier at the top are 6 feet by 30 feet, and all the faces batter at ½ inch to the foot. If the stratum upon which the caisson is to rest is 93⅓ feet below the top of the pier, and the height of the caisson from cutting edge to deck is 13 feet 4 inches, and the deck is to extend on all sides 6 inches outside of the base of the pier, what will be the dimension of the caisson floor? As the pier faces batter at a rate of ½ inch to the foot, the increase in each dimension will be as many inches as the pier is feet in height. The height of the pier is 93 ft. 4 in. − 13 ft. 4 in. = 80 feet. We, therefore, add 80 inches, or 6 feet 8 inches, to each dimension and we have for the base of the pier, length 36 feet 8 inches, and width 12 feet 8 inches. The caisson deck, which projects 6 inches on all sides beyond the pier base, will have a length of 37 feet 8 inches and a width of 13 feet 8 inches. The sides of the caisson are battered on all sides to reduce the friction of the earth against them during the progress of sinking. The total batter on each side is 12 inches. This batter will give to the base of the caisson the following dimensions, viz., length 39 feet 8 inches, and width 15 feet 8 inches. With the general dimensions of the caisson floor as determined above, the details may be modified to suit special conditions.

All caisson plans must meet certain requirements, viz.: There must be adequate supply shafts for admitting men and materials; air pipes for the compressed air, and a concrete shaft by means of which the concrete used in sealing and filling the caisson may be conveyed from the top of the masonry, where it is mixed, to the caisson chamber. Supply shafts are of boiler iron and from three feet to four feet in diameter, depending upon the size of the caisson. The

shafts are built in sections of from four to eight feet, the connections being made by means of exterior flanges, which are bolted together.

1566. Air Locks.—The shafts (usually two in number) are fitted with air locks, by means of which men and materials pass from the outer air to the caisson chamber, and *vice versa*, without the escape of the compressed air. The principle upon which the air lock is constructed is explained in Fig. 472.

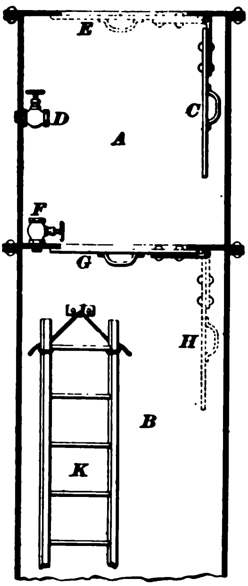


FIG. 472.

A is the air lock leading to the shaft *B*, which extends to the caisson chamber. A person entering the caisson finds the outer door in the position *C*. He first closes the air cock *D*, and swings the door shut, the door taking the position *E*. He then opens the air cock *F*, and the air in the lock *A* receives the pressure of the air in the caisson, forcing the door *E* firmly against the casing, which is usually fitted with a rubber gasket, making an air-tight joint. The pressure against the door *G* being removed, it opens of itself, taking the position *H*. The person is then in direct communication with the caisson chamber, descending to it by means of the ladder *K*. At the bottom of the shaft is another door, which is closed when the air lock at the surface is removed for adding another section to the shaft. One of the shafts is used for admitting men and tools, the other for removing material. The air lock used in removing material is provided with a windlass, the axle of which has air-tight bearings and extends through the sides of the lock, being fitted with two cranks which are operated by laborers. Most caissons are fitted with a sand pipe, by means of which the pressure of the air in the

caisson chamber is utilized in blowing out the sand or any fine material excavated in sinking.

1567. Plan of Caisson.—A general plan of a timber caisson is shown in Fig. 473, in which *G* represents the plan; *H* the longitudinal section, and *K* the cross-section. The walls *U* and *V*, enclosing the caisson chamber, are built of three courses of timber 12″ × 12″ square. The outer and inner courses consist of superimposed horizontal timbers extending the full length and width of the caisson. The inner course of timbers is laid in an upright position, and extends to within 1 foot of the top of the caisson deck. The timbers in the walls are securely bolted together with drift bolts, each bolt passing entirely through two timbers and penetrating fully 6 inches into the third. As the timbers are laid, they are poured with hot coal tar or pitch. At frequent intervals, the horizontal layers of timber are bolted to the upright timbers with screw bolts. The bolt heads must be countersunk and the sockets filled with pitch. Rubber washers are used to insure tight joints.

The cutting edge *a* is of $\frac{1}{4}$ inch boiler plate, 8 inches in width, and backed by 4-inch oak plank. The walls above the cutting edge increase in thickness with each course of timber, attaining their full thickness of 3 feet in the third course. When the caisson is of great size, longitudinal division walls are built dividing the caisson chamber into compartments. Openings are made in these walls to admit of free communication between the various compartments. The caisson shown in Fig. 473 has not sufficient breadth to require any interior division walls. Struts *Y* of 12″ × 12″ timber placed at intervals of about 8 feet insure lateral stiffness, and 2-inch iron tie-rods *Z* fitted with turnbuckles prevent the walls from spreading.

The deck consists of six courses of 12″ × 12″ timbers so laid as to render the chamber as nearly air-tight as possible, and give the greatest possible stiffness and strength to the structure. The first course *A* forms the ceiling of the chamber, the timbers extending the entire width of the

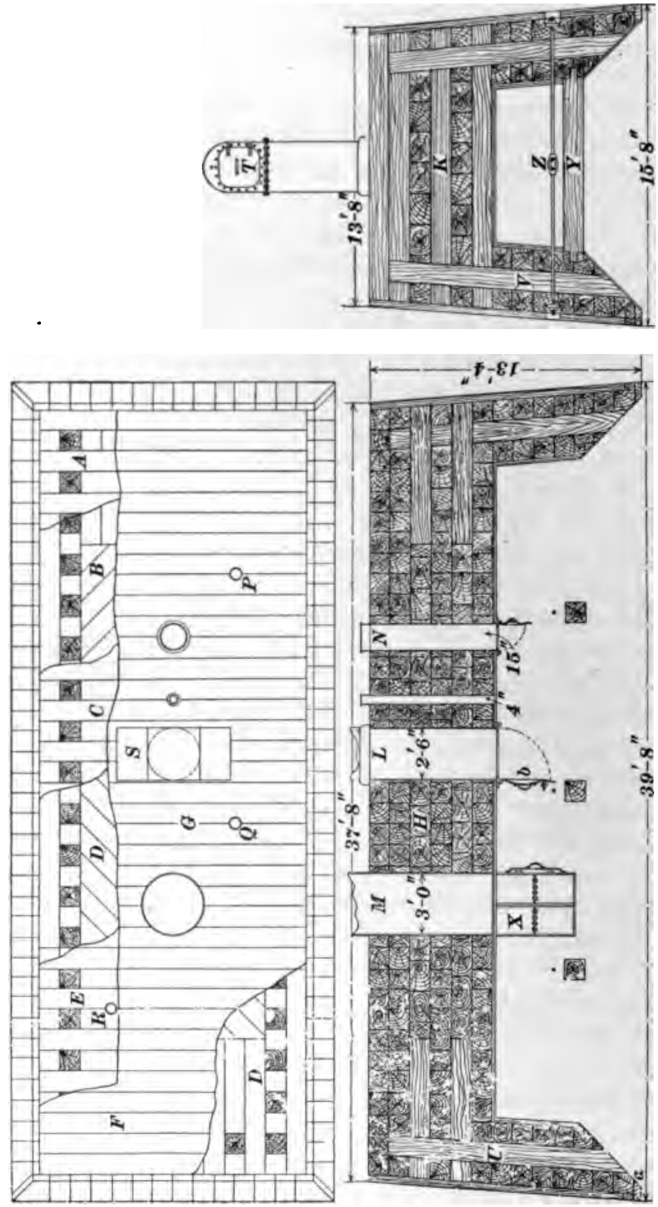


FIG. 473.

caisson. A layer of zinc enclosed between two layers of felt is laid over the entire ceiling course and ceiling, and floated with pitch. The timbers are laid close, with joints filled with pitch and fastened to the walls with heavy anchor bolts. Course *B* is laid diagonally to course *A* and bolted to it, a share of the bolts extending into the side walls. The diagonals stop at 6½ feet from the ends of the caisson. The balance of the course is laid longitudinally, with the alternate timbers passing between the uprights and extending to the outside sheathing of the caisson. Course *C* is laid transversely; course *D* diagonally, the diagonal timbers being at right angles to those in course *B*, and stopping at 6½ feet from the ends of the caisson, as in course *B*, and the balance of the course laid longitudinally, as in that course. Course *E* is laid transversely. Course *F*, forming the deck of the caisson, is laid transversely, and the masonry is started upon it.

An adz is used to give to the outside walls their proper batter. They are sheathed with 4-inch plank, tongued and grooved, the joints of which are filled with either hot coal tar or pitch. The sheathing affords a smooth outside surface, which greatly reduces the friction of the earth against the sides of the caisson. The timbers forming the inside walls and ceiling of the caisson chamber are first thoroughly calked and then covered with a layer of 1½-inch hemlock or spruce. This surface is then covered with tarred paper and a second layer of 1¼-inch matched spruce boards, with leaded joints. *L* and *M* are supply shafts—*L* for admitting men and tools, and *M* for removing excavated materials. *N* is a shaft for admitting concrete for sealing. The small shaft shown between *L* and *N* is an air pipe for conveying air from the compressor to the caisson chamber. The pipes *P*, *Q*, and *R* are sand pipes, by means of which sand and other fine material encountered in sinking may be forced out of the chamber by compressed air.

The air lock connecting with shaft *L* is shown in plan at *S*, and in elevation at *T*. It is fitted with exterior flanges, which fit the flanges of the sections of the shaft *L*.

Ordinarily the air lock *T* is used. When, however, the masonry has reached the height of the air lock *T*, the air lock *b* at the foot of shaft *L* is closed. The air lock *T* is then removed, another section of shafting added, and the lock again placed in position. The air lock *b* is then opened and the door fastened to the caisson ceiling. The air lock for shaft *M* is placed within the caisson chamber at *X*. This shaft is used in hoisting excavated material, which is placed in buckets and raised by a windlass placed on the top of the masonry. The buckets are filled and placed in the lock. Connection with the caisson chamber is then cut off, and the bucket hoisted to the surface.

The caisson is usually built near the shore, and when completed it is floated to the pier site, where it is held in position by strong hawsers fastened to cluster piles. The masonry is then started on the caisson deck, and the pressure of the air increased as the weight of the masonry causes the caisson to sink. As the caisson approaches the bed of the stream, it must be accurately located, so that when grounded it will take the exact position prescribed for it in the plan. Though of great weight, so long as the caisson floats, its position may be readily changed, but, once grounded, only a slight change of position is possible.

1568. Sinking the Caisson.—Once grounded in the proper position, the sinking of the caisson should be prosecuted with vigor. Since all excavated material must pass through an air lock, the process of hoisting it to the surface is necessarily slow.

After the enclosed area has been excavated to a depth of from 12 to 18 inches, the cutting edge of the caisson is undermined to an equal depth. The air pressure is then relaxed, and the weight of the caisson, together with its load of masonry, causes it to sink until it again rests on a firm footing. When the excavated material is sand, it is usually removed from the chamber by the sand pipe. To effect this a piece of flexible hose is attached at one end to the air pipe near the ceiling. The other end is fitted with a shear valve.

The sand is shoveled into piles, and the hose brought into direct contact with it. The valve is then opened, and the air pressure forces the sand through the hose and air pipe to the surface, where another piece of hose is attached, which carries the sand outside the masonry. When rock is encountered it is broken by blasting, and removed in buckets through the shaft. The rock encountered in sinking the caisson of the Washington bridge at New York was drilled with an air drill, the compressed air being furnished by the same plant which supplied compressed air to the caisson. Dynamite was used to break the rock. The caisson was lighted by electricity generated by a small dynamo stationed in the compressor house.

When the caisson is situated at a distance from the shore, the compressor plant is placed on a boat securely anchored at a short distance from the caisson.

1569. To Determine the Air Pressure in the Caisson.—The air pressure in a caisson must be sufficient to resist two external forces—the one due to the atmospheric pressure and the other due to the pressure of the water. The atmospheric pressure is taken at 15 pounds per square inch. The pressure of the water in pounds per square inch is found by multiplying the depth by .434. The sum of the two pressures will be the amount of the air pressure which must be maintained in the caisson in order to exclude the water.

EXAMPLE.—At a depth of 50 feet, what will be the working pressure in a caisson?

SOLUTION.—$.434 \times 50 = 21.7$; $21.7 + 15 = 36.7$ lb. Ans.

1570. Sealing the Caisson.—When the caisson reaches a secure foundation the process of sealing at once follows. This process consists in filling the entire chamber with concrete. The concrete is mixed on top of the pier and conveyed to the caisson chamber through the concrete shaft. This shaft or pipe is from 12 to 18 inches in diameter and fitted at both top and bottom with an air-tight door. While charging the pipe with concrete the bottom door is closed.

When the pipe is full the surface door is shut, the bottom door opened, and the contents of the pipe is discharged within the chamber. The concrete is then carried in wheelbarrows to the extremities of the chamber, which are first filled, the concrete being forced into every cavity. The chamber is completely filled from floor to ceiling, the space about the concrete pipe and shaft being left until the last. When the space has become too small to work in, the workmen leave the chamber, and the remaining space is readily filled with material from the top of the shaft.

PILE WORK.

1571. Pile Driving.—There is no subject connected with construction upon which there is so little accurate knowledge. This is partly accounted for by the fact that the material into which piles are driven lies below the surface of the ground, and exact knowledge of it is difficult to obtain.

Nor will a knowledge of the material into which the piles are driven enable the engineer to accurately measure the forces which give to the pile its bearing power.

The bearing power of a pile depends upon two things, viz.: *first*, the strength of the pile considered as a column, and, *second*, the friction of the ground against the sides of the pile.

1572. Pile-Driving Formulas.—A number of formulas for guiding engineers in pile work have been prepared by eminent engineers. Most of these formulas are more or less complicated. Some employ values which are difficult to obtain and are not suited to practical constructors. The following formula, published by the "Engineering News," and known as the *Engineering News' formula*, is very simple, and can be safely followed under all circumstances:

$$L = \frac{2\,w\,h}{S + 1}, \qquad \textbf{(109.)}$$

in which L = *safe load* in tons, pounds, or other units; w = weight of hammer in same unit; h = fall of hammer in feet; S = penetration of pile in inches at the last blow, and as-

sumed to be sensible at an approximately uniform rate (and head of pile in good condition, i. e., not split or broomed).

This formula gives a factor of safety of 6, i. e., the actual load which the pile can safely carry is only $\frac{1}{6}$ of its total bearing power, and is applicable to all forms of railroad construction from an ordinary trestle to a drawbridge pier or turntable foundation.

1573. Methods of Driving.—There are six methods of driving piles.

First Method.—Ordinary method, in which a hammer weighing from 2,000 to 3,000 pounds or more is dropped from a height of from 20 to 30 feet, falling free upon the head of the pile. Intervals between blows, from 5 to 20 seconds.

Second Method.—The same as first, except that the hammer is attached to rope which is slacked on the winding drum, allowing the hammer to fall. This method permits more rapid blows than the first method, but there is a loss of from 20 to 40 per cent. of the force of the blow, caused by the friction of rope on the drum and the hoisting sheave. It also admits of deliberate deception on the part of the contractor, who can check the fall of the hammer by the friction brake, delivering blows of not half the force which the amount of fall would indicate. This method is, however, very convenient and fair if properly used.

Third Method.—**By Water Jet.** In this a stream of water under pressure is ejected at or near the point of the pile, the water rising along the sides of the pile and removing nearly all the end and side resistance, so that the pile sinks by its own weight, though sometimes extra pressure is added. This method is specially adapted to compact sandy soils, and is often efficacious where all other methods fail.

Fourth Method.—**By Direct Pressure of a Constant Weight.** This method is applicable to soils of a wet silty nature (practically saturated with water).

This method is much employed in dock building at and in the neighborhood of New York. The method is sometimes

known as *pulling* down piles. In the mud of the Hudson river, it is almost impossible to drive a pile by ordinary methods, and the process of *pulling* is employed by placing part of the weight of a scow as an insistent weight upon the pile, which sinks it into the mud.

Fifth Method.—**By Nasmyth or Other Steam Pile Drivers.** In this the hammer weighs from 3,000 to 5,000 pounds. The fall is short, usually about 3 feet, but the blows are correspondingly rapid, usually about 60 per minute. Otherwise the principle is the same as Method 1.

Sixth Method.—**By Gunpowder Pile Driver.** In this each blow is a double one, the first caused by the fall of the hammer, and the second by the explosion of the powder on the head of the pile, which in turn throws the hammer upwards. By this method, there is scarcely any intermission in the downward movement of the pile.

1574. The Striking Force of the Hammer.—In calculating the striking force of the hammer, the resistance of the air and friction is not regarded. The leaders, i. e., the upright timbers between which the hammer works, are supposed to be vertical, and the hammer, held in place by well lubricated guides, falls about as freely as though unconfined. Thus, a 3,000-pound hammer falling a height of 20 feet will strike a blow of $3,000 \times 20 = 60,000$ ft.-lb.

1575. Interval of Time Between Blows.—Blows should be delivered at as nearly uniform intervals as possible, and the driving continued until the pile is completely driven. The effect of an interval of rest of even a few minutes is to permit the ground to settle about the pile, thereby greatly increasing its resistance to driving. This effect is most marked in fine, soft, and wet earth, and least in coarse gravel and sand. When driving in soft, wet soils, the penetration from last blow should not be taken for value of S, but after allowing an interval of rest, depending upon the action of the material upon the piles, the mean penetration from several blows should be taken.

1576. Effects of Broomed Heads.—According to best authorities, a broomed head will destroy from half to three-quarters of the effect of a blow, even where the brooming is not more than half-inch deep. To apply a formula, it will be necessary to adz or saw off the head of the pile so as to secure the full force of the hammer. Apply the formula to several cases, the average result of which may be depended upon.

1577. Effect of Driving with Hammer Attached to Rope.—The common practice of driving with hammer attached to rope is to be condemned. The force necessary to uncoil the rope from the drum and the friction of rope on hoisting sheave rob the blow of at least one-fourth of its force. In an actual case in practice, a pile penetrated 0.5 foot with a 40-foot fall of a 2,470 pound hammer with line attached to hammer and slacked on drum; it penetrated 0.7 foot when hammer was allowed to fall free, the gain in penetration from a free fall of hammer being 40 per cent. greater than when the hammer was attached to a rope.

1578. Pile Shoes.—In cases where piles are to be driven through a stratum of boulders, old cribwork, or any substance offering great resistance to driving, resort is frequently had to shoeing the piles with either cast or wrought iron. Common forms of shoes are shown in Figs. 474 and 475. The shoe in Fig. 474 is of wrought iron, the point


FIG. 474.


FIG. 475.

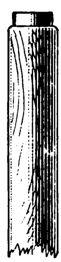


FIG. 476.

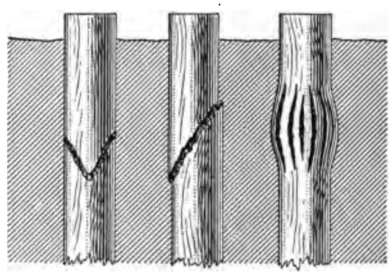


FIG. 477.

being fastened to the pile by spikes through the strap *s*. The shoe in Fig. 475 is an inverted cone of cast iron. The bolt

n, which fastens the shoe to the pile, is of wrought iron, the cone being cast around it. The flat base of the cone affords a good bearing for the foot of the pile. The practice of shoeing piles has of late years fallen into disuse. In a great many instances where shoes have failed, piles cut off square have driven fairly well. Shod or pointed piles are liable to cant or drive at an angle. In average ground a pile cut off square at the point will drive better, truer, and almost as rapidly as when pointed. There are, however, situations where either shoeing or pointing is absolutely necessary.

1579. Pile Hoops.—To prevent the pile from splitting while driving, the head is surrounded by an iron hoop from one-half to one inch thick and from 1½ to 3 inches wide, as shown in Fig. 476. They are, however, an uncertain security, especially in hard driving, when often the pile splits below the hoop and bulges to such an extent that it must be cut off before the driving can be continued.

1580. Slight Penetration Often Indicates Poor Driving.—When the penetration caused by a high fall of a heavy hammer is less than one-fourth inch with oak or one-half inch with soft wood piles, there is danger of over driving. A common mode of failure is shown in Fig. 477.

1581. Spacing Piles.—Bearing Piles, i. e., those used for foundations, should not be spaced less than three feet center to center; those spaced less than 2½ feet are worse than wasted. Where piles are overcrowded, the soil either becomes churned to a liquid mass or so compressed that those already driven are forced upwards while others are being driven. This effect sometimes occurs where the surface soil is underlaid with quicksand or soil of a buoyant nature, even where there is no overcrowding. A remedy for this trouble is often found in driving piles with the large end or top downwards. Where a considerable area is to be piled, those at the center should be driven first, then working towards the outside of the area. Where the reverse order is used, the soil of the enclosed area often becomes so compressed that piles *can not* penetrate it.

1582. Computing Loads.—Calling the average weight of masonry two tons per cubic yard, piles spaced three feet center to center will carry a wall of masonry from 50 to 75 feet in height. Piles spaced $2\frac{1}{2}$ feet center to center will support a wall of masonry from 75 to 100 feet in height. Greater loads are not warranted by good practice. Where a greater mass of masonry is required, the foundations should be stepped out so as to admit another row of piles, thus distributing the pressure over a greater surface.

EXAMPLE.—A double row of foundation piles carries an 18-inch masonry wall. The piles are spaced 3 feet center to center, i. e., as shown in Fig. 478, and driven with a 1,000-pound hammer, until a fall of 15 feet causes a penetration of one-fourth inch. What height of wall can be safely carried by the piles?

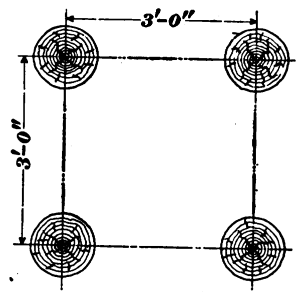


FIG. 478.

SOLUTION.—By formula **109**, $L = \frac{2wh}{S+1}$, we have L, safe load in tons; w, weight of hammer = .5 ton; h, height of fall of hammer = 15 feet; S, last penetration = $\frac{1}{4}$ inch. Substituting these values in the formula, we have $L = \frac{2 \times .5 \times 15}{.25 + 1} = \frac{15}{1.25} = 12$ tons, i.e., each pile will safely support 12 tons. Each yard in length of the wall is supported by two piles, which together can safely carry 24 tons. Taking the average weight of masonry at two tons per cubic yard, such a foundation would support an 18-inch wall 72 feet in height. Ans.

Modern depot buildings often carry roof trusses, which tax foundation piles to their safe limit.

1583. Trestle Loads.—In computing loads for *pile trestles* it is not too great an allowance to assume that the entire weight of the driving wheel base falls upon each **bent,** or row of piles, in succession. Suppose, for example, a bent of four piles is driven in building a trestle for heavy railroad traffic. In driving, a hammer weighing 3,000 pounds is given a free fall of 30 feet, and suppose the average penetration for the last three blows for the different piles is as follows:

First pile, $\frac{1}{2}$ inch; second pile, $\frac{3}{8}$ inch; third pile, $\frac{5}{8}$ inch; fourth pile, $\frac{3}{4}$ inch.

Applying formula **109**, $L = \frac{2wh}{S+1}$, we have

Safe load for 1st pile, $L = \frac{2 \times 1.5 \times 30}{.5+1} = \frac{90 \text{ tons}}{1.5} = 60.0$ tons.

Safe load for 2d pile, $L = \frac{2 \times 1.5 \times 30}{.375+1} = \frac{90 \text{ tons}}{1.375} = 65.5$ tons.

Safe load for 3d pile, $L = \frac{2 \times 1.5 \times 30}{.625+1} = \frac{90 \text{ tons}}{1.625} = 55.4$ tons.

Safe load for 4th pile, $L = \frac{2 \times 1.5 \times 30}{.75+1} = \frac{90 \text{ tons}}{1.75} = 51.4$ tons.

Total safe load for four piles.............. 232.3 tons.

Taking the weight on wheel base of a consolidation engine at 48 tons, which load each bent must successively carry, and dividing the combined safe load of the four piles, viz., 232.3 tons, by 48 tons, the weight on the wheel base, we have a quotient of 4.84, i. e., the bent is able to safely carry 4.84 times as great a load as it will ever be required to carry. The above values of S are much smaller than can be obtained in many soils. Often the penetration from the last blow is several inches. If, however, the piles are allowed to stand 24 hours and the earth to settle firmly about them before being tested with the hammer, it will usually require two or three heavy blows to start them. Supposing the average penetration for the last three blows on the above given piles had been, respectively, 2 in., 3 in., $3\frac{1}{2}$ in., and $2\frac{3}{4}$ in., the safe loads would have been the following, viz., 30 tons, 22.5 tons, 20 tons, and 24 tons, and the aggregate safe load 96.5 tons, which, divided by 48 tons, the weight on wheel base of locomotive, gives a quotient of 2.00 +, i. e., the trestle can safely carry twice as great a load as will ever be required of it.

1584. Piles Acting as Columns.—Piles penetrating through soft, yielding material into a comparatively hard, unyielding material act as columns, and should be given a

factor of safety not less than six. Assuming the weight of hammer at 3,000 pounds and the fall 20 feet, we have a blow of $3,000 \times 20 = 60,000$ ft.-lb., and for penetration of 1 in., 2 in., 3 in., 4 in., 5 in., and 6 in., the safe load in pounds by our formula is 60,000, 40,000, 30,000, 24,000, 20,000, 17,143 lb., respectively, which is about $\frac{1}{6}$ of the ultimate breaking load of a 10-inch column of wood of a height of 8 feet, 14 feet, 18 feet, 21 feet, 24 feet, and 26 feet, respectively. Where the length of the column without side support is greater than this and the safe load by the formula is less, in the same proportion will the safe load given by the formula exceed the safe load of the column, i. e., the safe load indicated by the penetration will be in excess of the load which an unsupported column can carry.

1585. Pile-Driving Machines.—Pile-driving machines are of two general classes, viz., **land machines** and **floating machines.** In both classes the framework of the pile driver is essentially the same. This framework consists of the upright timbers called the guides or leaders which hold the pile in position and between which the hammer rises and falls, the wooden bracing of the leaders, and the iron stayrods for the same.

The machinery for hoisting the hammer may be either a simple crab-winch or a stationary engine, or horse power may be used. For all important modern work a hoisting engine is used. The land machine (see Fig. 479) rests on longitudinal sills *A*, *A*, which in turn rest on rollers *B*. The hoisting machinery, contained in the house *C*, and the coal and water supply *D* and *E* are well to the rear of the framework. When a row of piles is driven, they are cut off at a fixed elevation and capped and temporary or permanent stringers laid. The pile driver is then moved forwards on its rollers, the leaders *F* projecting far enough beyond the last bent to reach the line of the next row of piles. The engine, boiler, coal and water supply, resting on the rear end of the framework of the machine, serve as a counterweight. The side braces *G*, *G* extend nearly to the heads of the

leaders, and foot upon the cross timber *H*, where they are securely braced with timber knees *K*, *K*. The back braces *L*, *M*, and *N* are bolted at top to the leaders and at bottom to the sills *O* and *P* and to the cross timber *Q*. The main back braces *L* are fitted with rounds, forming a ladder, by

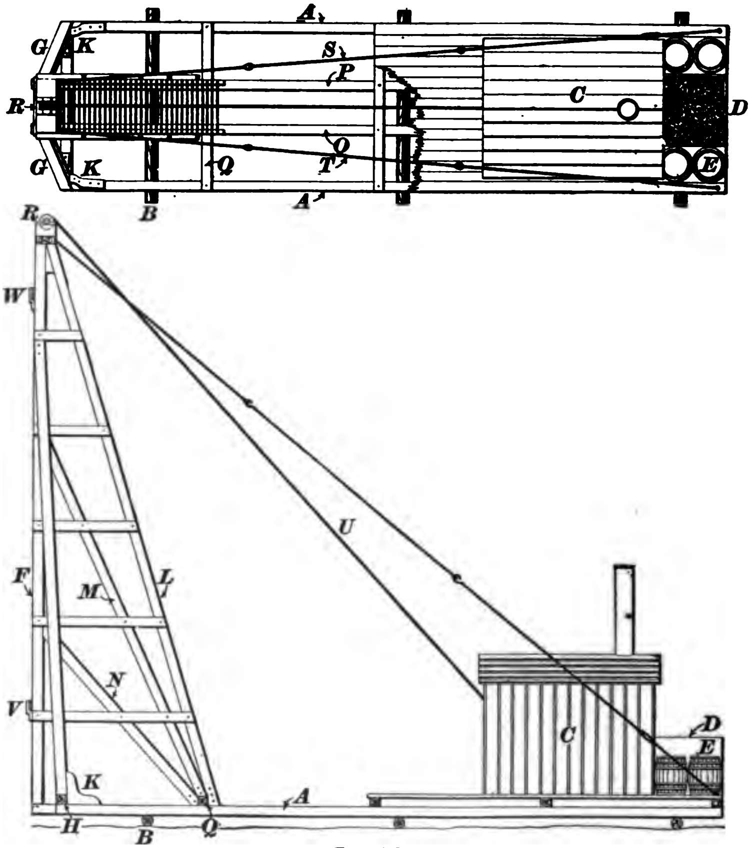


FIG. 479.

means of which ascent is made to the hammer sheave *R*. Stayrods *S* and *T*, fitted with turnbuckles, extend from the heads of the leaders to anchorages in the sills at the rear end of the framework. The hammer rope *U* winds on a drum not shown in the drawing. The brackets *V* and *W*

support cross-bars upon which the hammer rests when not working. The sizes of the timbers will depend upon the character of the work to be done and upon the length of the piles to be driven.

The floating machine (see Fig. 480) is carried on a powerfully built scow *A* of light draught. The machine shown is of the latest model, and the heaviest in New York harbor. The hull is 56 feet 6 inches long and 23 feet 6 inches wide over all; each of the sides of the hull is made of four pieces of yellow pine, the two lower 8 × 14 inches, the third 7 × 14 inches, the top piece 6 × 14 inches, all securely tied by through bolts.

The bow planking is oak 5 inches thick; the bottom and end plank, yellow pine 3 inches thick. The bow is further strengthened by a 16 × 16-inch cross timber at top, and at the stem is an 8 × 12-inch cross timber of yellow pine. Oak is used on the bow as being better adapted to stand the constant wear of the piles hauled against it. To prevent knots or inequalities on the piles from interfering with their position under the hammer, the bow planking overhangs 6 inches in its total height.

The hull is especially designed to obtain longitudinal stiffness so that the strain between the bow and engine may be properly distributed. To attain this end the hull is strengthened lengthwise by four longitudinal bulkheads, or keelsons *f*, each 6 inches thick and braced laterally by four sets of **X** braces *g*, made of 6 × 6-inch timber. The hull is further braced in the center by two 3 × 12-inch yellow pine braces *h*, and tie-rods or "log chains" *k* of iron $1\frac{3}{4}$ inches in diameter. Wale pieces and fender plank *l* 3 inches thick protect the outside of the hull against chafing; the deck has a crown of about 6 inches in its total width.

The leaders *m*, *m* are made of two pieces of 12″ × 12″ yellow pine 67 feet long from out to out, with inside guides *n* of 4 × 5-inch stuff protected by plate iron one-fourth inch thick; five-eighths inch bolts with countersunk heads fasten the inner guides to the main sticks and at the same time secure the iron work to the same. The bottoms of the leaders

are connected with the 12 × 12-inch bed pieces *o* by two timber knees not shown, and are tied at the top by the cap *p*.

The arrangement of the back braces *q*, *r*, and *s* is clearly shown in the elevation. Their dimensions are, respectively, 6 × 12, 5 × 10, and 5 × 12 inches. They are of yellow pine

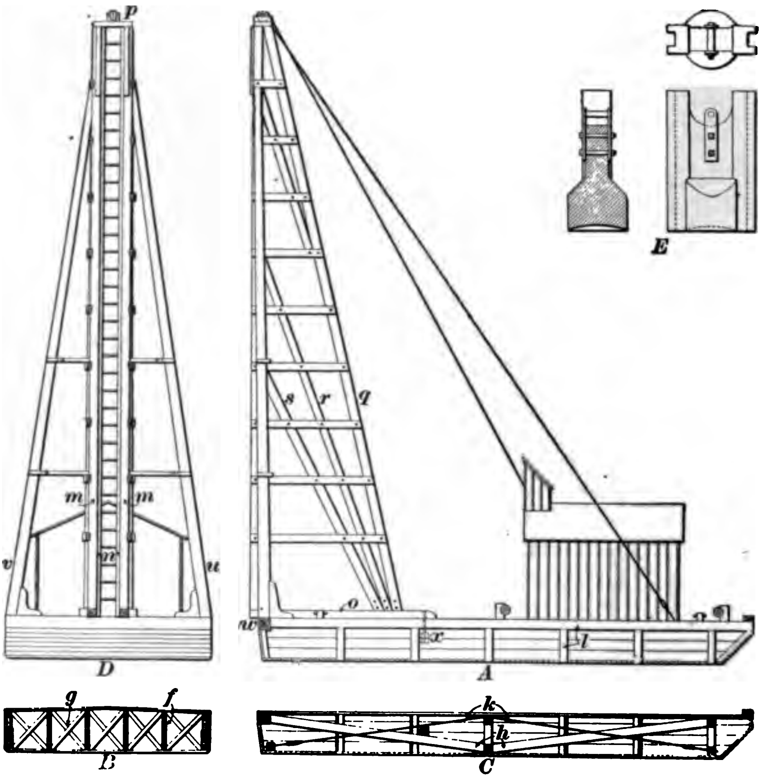


FIG. 480.

and securely bolted at the top and bottom with seven-eighths inch bolts.

The side braces *u* and *v* are of round timber 16 inches in diameter at butt, and each anchored to the hull by two heavy timber knees. The bed pieces *o* are fastened down to the hull by four bolts each one inch in diameter, the forward bolt passing through the 16 × 16-inch oak piece *w* on the

bow, and the after bolts passing through a cross timber x, 6×14 inches. The bottoms of the back braces are secured to the bed timbers by 1-inch strap bolt in each timber, the strap portion of the bolt being 2 inches $\times \frac{1}{2}$ inch in section. A seven-eighths inch through bolt ties the three braces together. The iron stayrods running from heads of leaders to the after part of hull are two in number, and each one inch in diameter.

The hoisting sheaves on top are two in number, placed side by side. They are 12 inches in working diameter, $15\frac{1}{2}$ inches from out to out, and $3\frac{1}{2}$ inches wide, and the pin passing through them is $2\frac{1}{2}$ inches in diameter at the sheaves and 2 inches in diameter in the boxes. These dimensions are none too great to stand the severe work frequently put upon the sheaves in hoisting heavy weights and tearing out timber. The fall or hammer rope is 2 inches in diameter, and the "runner" used in hoisting up piles is $1\frac{5}{8}$ inches in diameter.

The hoisting engine is double-drummed and of nominally 25 H. P. The detail of the hammer, shown at E, gives a clear idea of its general design. The weight is 3,300 pounds.

1586. Sheet Piles.—In building cofferdams for foundations and often in protection work, piles are driven in close contact to prevent leakage. Such piles are called

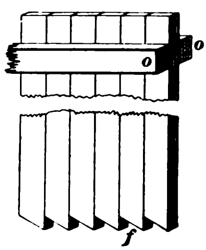


FIG. 481.

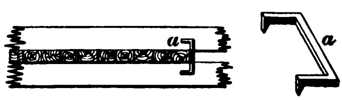


FIG. 482.

sheet piles. Sheet piles are always of sawed timber. Where the water is shallow and without a current, 2-inch planks will be sufficient. As the depth of water and pressure

increase, the dimensions of sheet piles increase. Usually they are thinner than they are wide, but frequently they are of square timber and as large as bearing piles, and are then called **close piles.**

To make sheet piles drive close together at foot, the points are sharpened as shown at *f* in Fig. 481. Any lateral movement is prevented by the wales *o*, *o*.

To keep the edges at top close to those already driven, a dog iron, such as shown at *a* in Fig. 482, is often used.

A cut of a standard sheet pile driver is given in Fig. 483. A general plan of cofferdam illustrating the use of

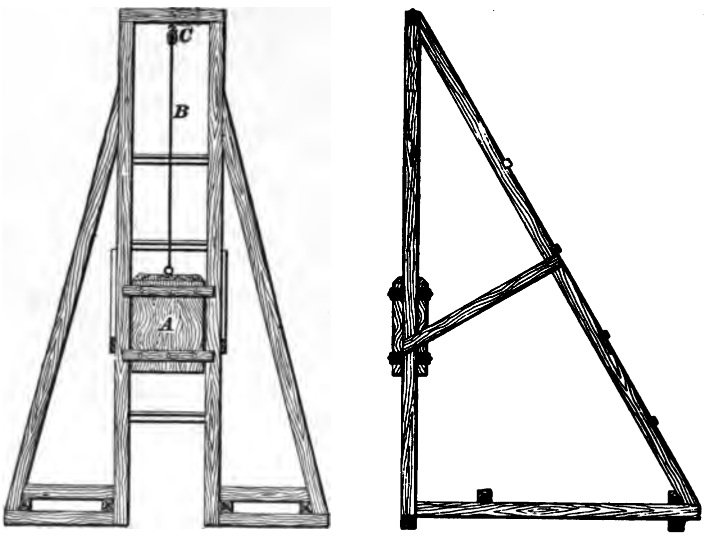


FIG. 483.

sheet piling was given in Fig. 465, Art. **1554.** The frame is light, and readily shifted by hand. The hammer *A* is oak. It is raised by the rope *B*, which works in the single pulley *C*. The hammer is usually worked by hand, three or four laborers generally being sufficient.

1587. Cost of Pile Driving.—The following figures on the cost of pile driving are taken from reports published in the *Engineering News* :

COST OF LABOR IN DRIVING PILES IN BRIDGE CONSTRUCTION.

Kinds of Labor.	Pile Bridge on Land.	Temporary Bridge.	Draw Fender and Ice Breaker.	Pivot Pier.	River Pier.
Preparations and repair of plant...........	$68 95	$63 65	$53 50	$37 00	$61 60
Driving..................................	432 70	252 92	430 50	515 45	565 80
Sawing and straightening................	78 75		47 50	*179 80	†131 90
Total cost	$580 40	$316 57	$531 50	$732 25	$759 30
Number of piles in structure	224	102	184	121	167
Total number of feet remaining in structure	7.238	3.710	7.023	4.639	7.316
Average length of piles remaining in structure..................................	32.3		38.2	38.4	43.8
Average length of piles cut off	1.1		4.1	6.6	3.7
Cost per foot of piles remaining in the structure............................	8.0c.	8.5c.	7.6c.	15.8c.	10.4c.

Average *cost* for *driving per foot* remaining in the structure, 9.76 cents.

* Sawed off under 8 feet of water.

† Including $70.25 for excavation and bailing in order to get at the sawing.

Cost of Piles.—At Chicago, and points on the Mississippi river at and above St. Louis, pine piles cost from 10 to 15 cents per lineal foot, according to length and location. Soft wood piles, including cottonwood, rock elm, etc., can be had at any point for from 8 to 10 cents per lineal foot. Oak piles 20 to 30 feet long cost from 10 to 12 cents per foot; 30 to 40 feet long, from 12 to 14 cents; 40 to 60 feet long, from 20 to 30 cents per foot.

The tables of cost which follow are for various classes of work.

Railroad Construction.—The accompanying table of cost is exclusive of first cost of piles and of the expense of hauling. Piles used in construction of the Chicago branch of the Atchison, Topeka and Santa Fe Railroad. Piles were driven ahead of the track by a horsepower drop hammer weighing 2,200 pounds. Average depth driven, 13 feet. Table includes cost of driving piles for foundations of Howe truss bridge, and for false work used in the erection of same. The contractor received the same price for all classes of work. The work was varied, the piles being driven into all kinds of soil. Wages for labor were high, and as follows: Foreman, $4 per day; six laborers, at $2; two teams at $3.50; total cost for labor, $23 per day. Work in progress in the year 1887.

Number of piles included in report	4,409
Number of lineal feet included in report	109,578
Average length of piles in feet	24.8
Number of days employed in driving	491
Number of lineal feet driven per day	223.2
Cost of driving, per pile	$2.53
Cost of driving, per foot	10.2 cents

Bridge construction, Northern Pacific Railroad bridge over Red River, at Grand Forks, Dakota, constructed in 1887. Soil, sand and clay. The penetration under a 2,250 pound hammer, falling 30 feet, was 2 to 4 inches. The foreman received $5 per day, stationary engineer $3.50 per day, and laborers $2 per day.

In the construction of a railroad in Southern Wisconsin during 1885-87, the contract price—the lowest competitive bid—for piles in place under the piers of several large bridges, averaged as in the following table. The piles were driven in a strong current and sawed off under water; hence, the comparatively great expense:

CONTRACT PRICE FOR FOUNDATION PILES.

Material of Pile.	Kind of Driving.	Contract Price per Lineal Foot.	
		For Part Remaining in Structure.	For Pile Heads Sawed Off.
Rock Elm	Ordinary	40 cents.	15 cents.
Pine	Ordinary	40 cents.	20 cents.
Oak	Ordinary	48 cents.	25 cents.
Oak	Hard	50 cents.	30 cents.

ESTIMATES.

1588. Calculating Cross-Sections.—Cross-sections are the basis of most calculations employed in determining the amount of material handled in grading the roadway. A full description of the method of taking and recording cross-sections was given in Arts. **1457** and **1458.** The cross-section notes are copied into a *Quantity Book*, and the total end areas of the cross-sections, together with the partial areas representing the classification of the material as determined by the excavations, are placed in regular order. On the same line, under their proper headings, are placed the quantities of the different materials excavated between the two points of the line where the cross-sections are taken.

The common practice in calculating quantities from cross-sections is to multiply the mean or average area in

square feet of two consecutive sections by the distance in feet between them.

Thus, let A represent the area in square feet of one section; B, the area in square feet of the next section; C, the number of feet between the sections, and D, the total number of cubic feet in the prismoid lying between these sections. Then, by common practice,

$$D = \frac{A + B}{2} \times C. \qquad \textbf{(110.)}$$

EXAMPLE.—Two consecutive cross-sections are 50 feet apart. The area of one is 150.4 square feet, and of the other is 191.3 square feet. What is the volume of the included prism ?

SOLUTION.—Substituting the given quantities in the above formula,

$$D = \frac{A + B}{2} \times C,$$

we have volume $= \dfrac{150.4 + 191.3}{2} \times 50 = 8{,}542.5$ cu. ft. $= 316.39$ cu. yd. Ans.

1589. The Prismoidal Formula.—A more accurate result is obtained by the use of the prismoidal formula. In applying the prismoidal formula to the calculation of cubic contents, it is requisite to know the middle cross-section between each two that are measured on the ground. The dimensions of this middle section are the mean of the dimensions of the end sections.

Calling one of the given sections A, the other B, the middle section M, the distance between the sections L, and the required contents S, we have, by the prismoidal formula,

$$S = \frac{L}{6}(A + 4M + B). \qquad \textbf{(111.)}$$

In calculating the cubical contents of the prismoid included between the following sections, both methods of calculation will be used and the two results compared. The sections are represented by Figs. 484 and 485, and are denoted by the letters A and B. The perpendicular distance between them is 50 feet. The section given in Fig. 484 is composed of the four triangles a, b, c, and d. The triangles

a and *b* have equal bases of 9 feet, the half width of the roadway; hence, if we take half the sum of their altitudes and multiply it by the common base we shall have the sum of the areas of the triangles *a* and *b*.

The triangles *c* and *d* have a common base 8 feet, the center cut of the section, and if we take the half sum of the side distances and multiply it by 8 feet, we shall obtain

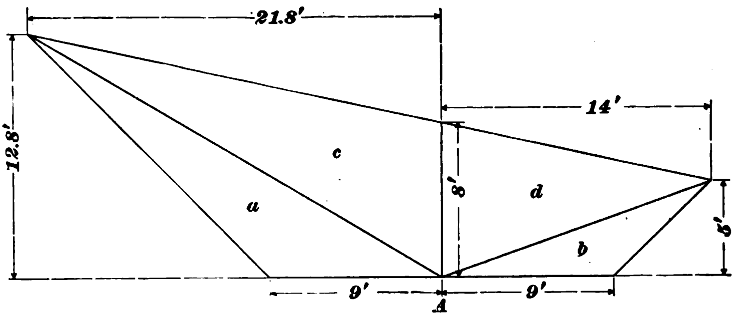


FIG. 484.

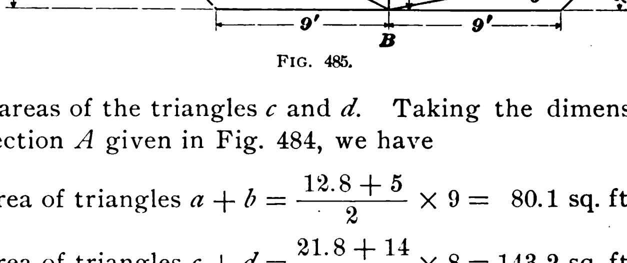


FIG. 485.

the areas of the triangles *c* and *d*. Taking the dimensions of section *A* given in Fig. 484, we have

$$\text{Area of triangles } a + b = \frac{12.8 + 5}{2} \times 9 = 80.1 \text{ sq. ft.}$$

$$\text{Area of triangles } c + d = \frac{21.8 + 14}{2} \times 8 = 143.2 \text{ sq. ft.}$$

$$\text{Total area of section } A = 223.3 \text{ sq. ft.}$$

Taking the dimensions of the section *B* given in Fig. 485, we have

Area of triangles $a' + b' = \frac{9.7 + 2.2}{2} \times 9 = $ 53.55 sq. ft.

Area of triangles $c' + d' = \frac{18.7 + 11.2}{2} \times 5 = $ 74.75 sq. ft.

Total area of section B = 128.3 sq. ft.

Mean area of sections A and $B = \frac{223.3 + 128.3}{2} = 175.8$ sq. ft.

Contents of the included prismoid = $175.8 \times 50 = 8{,}790$ cu. ft. = 325.6 cu. yd.

In applying the prismoidal formula we calculate the area of a section midway between the given sections, and for its dimensions we take the mean of the dimensions of the given sections. These dimensions will be as follows:

Center cut, $\frac{8 + 5}{2} = 6.5$ ft.

Right side distance, $\frac{14 + 11.2}{2} = 12.6$ ft.

Left side distance, $\frac{21.8 + 18.7}{2} = 20.25$ ft.

With these dimensions, construct the section M shown in Fig. 486.

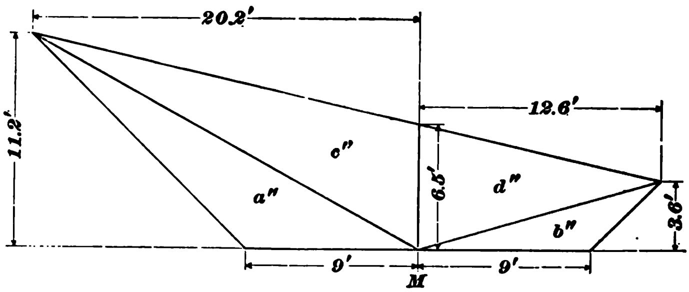


FIG. 486.

The area of section M is computed by the same method as that used with sections A and B in Figs. 484 and 485, and is as follows:

$$\text{Area of triangles } a'' + b'' = \frac{11.2 + 3.6}{2} \times 9 \quad = \quad 66.6 \text{ sq. ft.}$$

$$\text{Area of triangles } c'' + d'' = \frac{20.2 + 12.6}{2} \times 6.5 = 106.6 \text{ sq. ft.}$$

$$\text{Total area of section } M = \qquad 173.2 \text{ sq. ft.}$$

Denoting the distance between the sections by L, and the cubical contents of the prismoid by S, we have, by applying the prismoidal formula **111**,

$$S = \frac{L}{6}(A + 4M + B).$$

Substituting known values in the formula, we have $S = \frac{50}{6}(223.3 + 4 \times 173.2 + 128.3) = 8{,}703$ cu. ft. $\doteq 322.3$ cu. yd. Ans.

Comparing the results, we have

By averaging end areas, contents = 325.6 cu. yd.
By prismoidal formula, contents = 322.3 cu. yd.
A difference of about 1 per cent.

Fig. 487 represents a mixed section of which the part $a\ b\ c$ is solid rock, the part $c\ d\ e\ f$ is loose rock and the part $d\ e\ g\ h$ is earth. The slope $a\ c$ in solid rock is $\frac{1}{4}$ horizontal to 1 vertical. In a section where the excavated material is classified, the foregoing methods of computing areas can not be employed except to check the aggregate area, and when the slopes vary with the different materials other methods must be entirely used.

Where there is no indication of rock, the slope stakes are set to the usual slope of 1 horizontal to 1 vertical. If rock is encountered before the rock excavation is commenced, the slope is contracted to $\frac{1}{4}$ horizontal to 1 vertical.

It has been customary to plat irregular sections on cross section paper. The original or surface cross-sections are first platted, and when the top material (usually earth) has been removed, a cross-section of the remaining material is taken and platted on the original sheet, the lines being

drawn in colored ink. If there is still another classification of material, as shown in Fig. 487, a final cross-section is taken and platted in lines of a separate color.

The different colored lines at once indicate the outlines of the various materials and assist in checking the calculations of the partial areas. The original cross-sections and the finished section should be in black, the others in distinct, separate colors.

The partial areas are easiest calculated by dividing them into triangles and carefully scaling all dimensions not given.

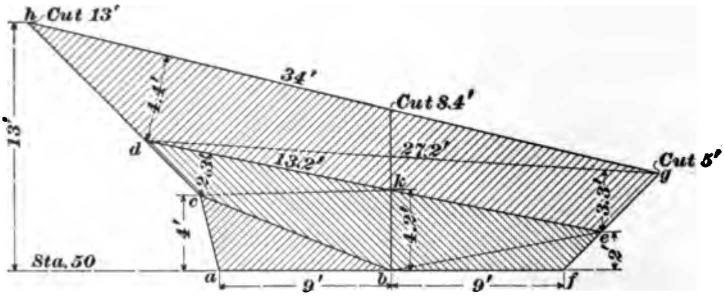


FIG. 487.

In Fig. 487 we have, remembering that the slopes of fg and ch are 1 to 1:

			Total.
Area of triangle $a\ b\ c$ of solid rock =	9×2	= 18.0 sq. ft.	18.0 sq. ft.
Area of triangle $b\ e\ f$ of loose rock =	9×1	= 9.0 sq. ft.	
Area of triangle $b\ e\ k$ of loose rock =	11×2.1	= 23.1 sq. ft.	
Area of triangle $c\ b\ k$ of loose rock =	10×2.1	= 21.0 sq. ft.	
Area of triangle $c\ d\ k$ of loose rock =	13.2×1.15	= 15.2 sq. ft.	68.3 sq. ft.
Area of triangle $d\ e\ g$ of earth =	27.2×1.65	= 44.88 sq. ft.	
Area of triangle $d\ g\ h$ of earth =	$34.\ \times2.2$	= 74.8 sq. ft.	119.7 sq. ft.
Total area of section			206.0 sq. ft.

1590. Quantity Books.—Quantity books spoken of in Art. **1588** are of various forms. The following is recommended. It contains station and cross-section notes of Fig. 487, together with the end areas:

Station.	Cross-Sections.			End Areas (Square Feet).					Quantities (Cubic Feet).			
				Cut.				Fill.	Cut.			Fill.
	Left.	Center.	Right.	Earth.	Loose Rock.	Solid Rock.	Total Area.		Earth.	Loose Rock.	Solid Rock.	
50	C $\frac{13.0}{19.0}$	C 8.4	C $\frac{5.0}{14.0}$	119.7	68.3	18.0	206.0					

This form of notes includes both left and right-hand pages of the book, and the classification of material meets the requirements of most railroad work. When the material included between two consecutive cross-sections is of the same character, the *prismoidal formula* should be used in calculating the cubical contents of the included prismoid, but when the sections are classified, as in Fig. 487, the mean area of each material shown in both sections should be taken and multiplied by the distance between the sections. When one kind of material, such as rock, shows in one section and not in the next following, the point where that particular material ends should be determined and the distance from it to the section containing rock should be measured. This mass of rock will be considered either as a pyramid or a wedge, according to its form. When of wedge form, its volume is the product of its base by one-half its altitude or length; and when of pyramid form its volume is the product of its base by one-third its altitude or length.

The partial and total areas of each section are placed on the same line under their proper headings. As the number of the station at which each cross-section is taken is given in the station column, the distance between any two sections is readily found by subtraction. The quantities are carried out on the same line as the end areas and placed under their proper headings. Thus, in calculating the material between Sta. 50 and Sta. 50 + 50, place the quantities on the Sta. 50 + 50 line, which is next below Station 50. When a page of the quantity book is filled, add the several columns of quantities which are given in cubic feet, and reduce them to cubic yards by dividing by 27. At the end of each mile section a blank page should be left in the quantity book. A summary of the total yardage of each kind of material handled in the grading of the section is then made out and placed on this blank page, together with the contract price and value of the work. Wherever a trestle or culvert occurs, a space should be left in the quantity book at the proper station, large enough to contain a sketch and estimate of the materials for the same. Spaces should also

be left for borrow pits and any special excavation. All these partial estimates will appear in the summary in proper order. The following will serve for a guide:

SUMMARY OF QUANTITIES.

SECTION 10.

Excavation.

Earth	10,000	cubic yards @	20c.	$2,000.00
Loose rock	1,500	cubic yards @	40c.	600.00
Solid rock	850	cubic yards @	80c.	680.00
Borrow	2,000	cubic yards @	20c.	400.00

Masonry.

First-class	190	cubic yards @	$10.00	$1,900.00
Second-class	220	cubic yards @	6.00	1,320.00
Rubble	270	cubic yards @	4.00	1,080.00
Rip-rap	300	cubic yards @	60c.	180.00
Paving	120	sq. yd. @	90c.	108.00

Piling.

4,000 lineal feet @ 30c. $1,200.00

Trestle Timber.

100,000 feet board measure, in work @ $30...... $3,000.00

Iron.

3,000 pounds @ 4c. $120.00

Total cost of grading, masonry, and trestling on Section 10................................$12,588.00

1591. Monthly Estimates.—On or about the last day of every month during the progress of construction, measurements are taken to determine the total amount of work done and materials furnished up to that date. It is frequently necessary to take measurements for both monthly and final estimates at other times than the closing days of the month. This is especially the case in foundation work where the masonry is started as soon as the excavations are completed. When the roadway has been completed, the

monthly and final estimate will be the same. The quantities are taken directly from the *quantity* book, where end areas of sections and volumes are carefully calculated and carried out in regular columns.

An approximate estimate is made of all work in progress, care being taken to make it as exact as the nature of the work will allow.

A **special field book** is used for monthly estimates, in which a description is given of the particular work or structure measured, together with the date of measurement. The notes consist principally of the cross-sections of incompleted roadway. Wherever the roadway is completed to grade, the word "completed" is commonly written opposite the station and the quantities computed from the original cross-sections. Notes of foundation pits are made doubly clear by a sketch of the excavation with dimensions marked on the outlines. All special work, concerning which a misunderstanding may possibly arise, must be particularly described.

Materials, such as lumber, stone, etc., furnished by the contractor and not put into any structure at the time the estimate is taken, should be measured and the amounts placed under the head of *temporary allowances*, the price allowed being somewhat less than the actual value of the material as delivered.

Blank forms are used by the resident engineer in reporting monthly estimates. In these forms a column is provided for each of the different classes of material and work contained in the contract. The stations are numbered in the first column in regular order, and opposite each station in the proper column the amount of excavation, masonry, etc., is written.

An estimate is made for each particular mile section into which the line of railroad is divided for letting.

The resident engineer should keep, in a separate book, a record of each monthly estimate.

The monthly estimates are forwarded to the *division engineer*, who reviews them, copying the footings of the several

columns into a separate book in which the sections of his division are placed in regular order. The prices are affixed to the quantities and the total amounts carried out. From the totals, the amounts of previous estimates are deducted, and the remainder is the amount due the contractor for the month. From this amount a certain percentage (usually 15 per cent.) is deducted to be reserved by the company until the completion of the contract.

A summary of the monthly estimate is then forwarded by the division engineer to the chief engineer for auditing and approval.

1592. The Final Estimate.—The final estimate is a complete statement in detail of the amount of work done and the materials furnished in the construction of the road, and is the basis of final settlement between the company and the contractor. It should be commenced as soon as construction is under way and continued as fast as the necessary data may be collected.

Full notes must be kept of each particular structure and complete measurements taken while the work is under way and the circumstances fresh in mind. This is particularly important in the case of bridge and culvert foundations and other structures, either under water or covered with earth at the completion of the work. These sketches and notes will be recorded at their proper station in the **quantity book** described in Art. **1590.** When the work is completed, a final summary is made containing the aggregate quantities of the entire line.

Full notes are kept of all classified materials and of all material affected by length of haul (providing a haul clause occurs in the contract) and arranged in the order in which the work occurs on the line.

The calculations for final estimate limit the monthly estimates and guide the engineer in making approximate estimates of either work or material.

TRACK WORK.

TRACK LAYING.

1593. There is no department of modern railroad engineering which is receiving so much attention as the care and maintenance of the track. In the great strife for business, freight and passenger rates have been reduced to a minimum, and to meet these conditions speed and train loads have been nearly doubled. These conditions demand a **good track.**

A track to be *good* must be laid on sound ties, well ballasted and surfaced, full spiked and bolted, and in perfect line and surface.

1594. New Road.—In America practically all newly constructed railroad is built of new material throughout, though the cross-ties are often cheap and the rails light.

CROSS-TIES.

1595. Cross-ties are of wood. Their size and variety of timber will depend upon the locality and financial ability of the railroad company. The best ties are of *white oak.*

The following list gives in a descending scale the comparative values of woods for cross-ties:

Hard Wood.	Soft Wood.
White Oak.	Red Cedar.
Rock Oak.	Black Cypress.
Burr Oak.	White Cedar.
Chestnut.	White Cypress.
Southern Pine.	Tamarack.
Walnut.	Butternut.
Cherry.	White Pine.
Red Beech.	Hemlock.
Red Oak.	Spruce.

It is generally accepted that hewn ties are superior to sawed ties. The surface of a well-hewn tie is a series of comparatively smooth surfaces. The effect of the ax is to close the pores as the chip is removed, which tends to exclude the moisture. The effect of the saw is exactly the reverse of the ax. While given an average smoother surface, it tears the fiber of the wood, leaving the pores open. These minute broken fibers which cover the entire surface of the tie act like sponges in attracting and retaining moisture, and eventually hasten decay.

1596. Importance of Seasoning.—Too little attention is paid to the seasoning of cross-ties before they are laid in the track. This is especially true on newly constructed lines where scarcity of capital and the necessity for keeping down expenses compel the use of the cheapest material and methods. Cross-ties thoroughly seasoned will last fully one-quarter longer than those used while green, and they are better in every way. Well-seasoned wood will hold the spikes better and resist the shearing tendency of the rails due to passing loads better than green ties. The most favorable months in Northern latitudes for cutting ties are August, December, January, and February. During these months there is comparatively no movement in the sap of the trees. The ties should be hewn to uniform thickness and piled in square piles about 4½ feet in height, as shown in Fig. 488, so as to admit of the free circulation of the air and to hasten the seasoning process.

FIG. 488.

1597. Specifications for and Inspection of Cross-Ties.—Specifications should include dimensions, and kind and quality of timber. Ties for standard gauge tracks should be from 8 to 9 feet in length, from 6 to 8 inches in thickness, and show not less than 6 inches of face. The

standard tie is 8 feet 6 inches in length, 7 inches in thickness, and shows at least 7 inches of face. In the Northern, Middle, and Western States, **log ties,** i. e., ties cut from entire trees and showing two rounded sides, are principally used. In the Southern, Atlantic, and Gulf States, yellow pine ties are in almost universal use. They are square hewn and made of heart timber, not more than 1 inch of sap being allowed on the corners. In Southern latitudes, where the process of decay goes on throughout the year, sap timber is almost worthless. The sap timber soon softens, the spikes loosen and the rails cut into the wood, leaving the track in a dangerous state. In those portions of the South where oak is abundant, oak ties are much used. They are generally square hewn. This is a mistake, especially if the ties are cut from young thrifty trees (and no other timber should be used), since a considerable portion of the weight of the tie is sacrificed in squaring. This lost weight is all needed to give stability to the track. The ties should be cut off square and to uniform lengths, and be of a uniform thickness throughout their entire lengths. Before being inspected, they should be delivered along the right-of-way of the railroad and piled in regular piles, each tie showing both ends. Ties are commonly graded as firsts and seconds. The inspector carries a brush and pot of paint, marking each class of ties with a distinctive mark. Firsts are usually marked by a full circle, and seconds by a cross.

PREPARATION OF A ROADBED.

1598. It is a rare thing to find a new roadbed in proper condition for track laying. Often it is in poor surface, being left by the contractors in a rough, uneven state. If the track is being laid in heavy, wet weather and the ties are being distributed by teams, the wheels are sure to cut deeply into the roadbed, and unless some precaution is taken to bring the tops of the ties to a uniform surface, there is great danger of the rails being bent by the passage of the construction train.

1599. Track Centers.—Center stakes marking the alinement are driven at intervals of 100 ft. on tangents and 50 ft. on curves, where the degree of curve does not exceed 12°. On curves exceeding 12°, stakes should be driven at intervals of 25 ft. A tack is driven in each stake, marking the center of the track. Grade stakes for surfacing ties should be placed at intervals of 16 ft. A straight edge placed upon these stakes marks the grade for the intervening ties. The ties are bedded with earth taken from the roadbed and tamped with the shovel.

The placing of grade stakes so close together is contrary to common practice, but the increased labor for the engineer is more than compensated for by the saving of the time ordinarily consumed in sighting in ties where grade stakes are set at intervals of 50 or 100 ft. The surface is sure to be better where the straight edge is brought into use, and the danger of kinking rails or bending them out of surface is obviated.

1600. Track - Laying Machines.—Track - laying machines have been used to some extent. The ties, as well as rails and fastenings, are carried on cars. With some machines they are conveyed to the front on rollers; in others, on an endless belt which runs along the sides of the cars. The process of track laying is as follows: Two rail lengths are laid, bolted, and partially spiked, and the ties partially bedded. The cars are then run forwards and the process repeated. The progress of track laying with a machine is limited by the amount of track which can be full bolted, spiked, and made fit for the running of trains, and ranges from 1 to 1½ miles per day, 1 mile being a common average. Economy in the force of track layers and the saving of team work are the principal advantages claimed for track-laying machines. In mountainous country, where the roadbed is difficult of access to teams, the track-laying machine has decided advantages over ordinary methods, but in open country where the roadbed is readily accessible, both ties and rails should be hauled by teams. With

material distributed a considerable distance in advance of the construction train, a much larger force of men may be economically employed. If the track laying is to be rushed, the track-laying machine must take second place.

1601. Track-Laying Outfit.—Before starting out to lay new track on a new road, the boss track layer should make requisition for all the tools necessary for expeditious work. These tools are loaded on a car and shipped to the point where work is to be commenced. Everything should be in readiness for making a good beginning before the men are brought on the ground. Any lack of proper tools is certain to cause awkward and often serious delay, and operations must often be suspended until the lack can be supplied from headquarters. The following list of tools will amply supply a force of 100 track layers, with a reserve for extra men in case they should be needed, and will be sufficient to take the places of tools worn out or broken until a supply can be brought to the front:

Hand cars	1	Covered water barrels	2
Steel cars	3	Track levers	2
Push cars	2	Chalk lines	2
Shovels	150	Spirit levels	6
Picks	50	Tape lines	6
Lining bars	12	Nail hammers	3
Claw bars	12	Monkeywrenches	3
Tamping bars	12	Lanterns, red	3
Nipping bars	24	Lanterns, white	3
Cold chisels	24	Water pails	6
Rail punches	6	Tin dippers	6
Chopping axes	6	Oil cans	2
Hand axes	6	Oilers	3
Striking hammers	42	Gallons of oil	2
Bush scythes and snaths, each	3	Pick handles	24
Hand saws	6	Nails, 10 penny, kegs	1
Adzes	6	Nails, 20, 40, 60 penny, kegs, of each	1
Track gauges	12	Cross-cut saws	2

1599. Track Centers.—Center stakes marking the alinement are driven at intervals of 100 ft. on tangents and 50 ft. on curves, where the degree of curve does not exceed 12°. On curves exceeding 12°, stakes should be driven at intervals of 25 ft. A tack is driven in each stake, marking the center of the track. Grade stakes for surfacing ties should be placed at intervals of 16 ft. A straight edge placed upon these stakes marks the grade for the intervening ties. The ties are bedded with earth taken from the roadbed and tamped with the shovel.

The placing of grade stakes so close together is contrary to common practice, but the increased labor for the engineer is more than compensated for by the saving of the time ordinarily consumed in sighting in ties where grade stakes are set at intervals of 50 or 100 ft. The surface is sure to be better where the straight edge is brought into use, and the danger of kinking rails or bending them out of surface is obviated.

1600. Track-Laying Machines.—Track-laying machines have been used to some extent. The ties, as well as rails and fastenings, are carried on cars. With some machines they are conveyed to the front on rollers; in others, on an endless belt which runs along the sides of the cars. The process of track laying is as follows: Two rail lengths are laid, bolted, and partially spiked, and the ties partially bedded. The cars are then run forwards and the process repeated. The progress of track laying with a machine is limited by the amount of track which can be full bolted, spiked, and made fit for the running of trains, and ranges from 1 to 1½ miles per day, 1 mile being a common average. Economy in the force of track layers and the saving of team work are the principal advantages claimed for track-laying machines. In mountainous country, where the roadbed is difficult of access to teams, the track-laying machine has decided advantages over ordinary methods, but in open country where the roadbed is readily accessible, both ties and rails should be hauled by teams. With

distance from the center line and stretched taut, being fastened at suitable intervals by well-driven stakes. Joints should not be located at any considerable distance in advance of the rails, as the measurements are likely to vary a little and soon accumulate an error. These inaccuracies are obviated by checking the measurements frequently from the ends of the rails already in place in the track. Care must be taken to place the ties at right angles to the center line. Ties laid askew prevent proper gauging of the track. Ties should be assorted with reference to thickness in order that those of uniform thickness may come together in the track, thus greatly reducing the labor of bedding.

1603. Bedding Ties.—As soon as the ties are distributed and lined they are bedded for the rails. The process is as follows: The straight edge is placed on the grade stakes and the faces of the ties brought to a uniform surface by first sinking those which are above grade and then raising those remaining to grade by throwing dirt or ballast under them and settling them to the correct level. It has been a general and most pernicious custom to spike the rails to the ties without bedding. Most rails will be found to carry from one to a half dozen swinging ties, some of which are sure to get skewed before the ballast secures them. The track is full of undulations and as the foundation is rough and uncertain, many of the rails are kinked or surface-bent by the passing construction train. Where ties are bedded, the spiking can be better and more expeditiously done, and the construction train can follow at once with entire safety.

If the track is to be ballasted with cinders or broken stone, the ties must not be bedded, in order that the ballast may occupy all the vacant space in the roadway. Nevertheless, the dressing down of uneven places in the roadway before distributing the ties is time and money well spent. The ballasting must be kept well up with the track laying if kinking of the rails is to be avoided.

1604. Organization of Forces.—The foreman in charge of track-layers should thoroughly organize his forces,

placing each man where his work will give the best results. Spikers and iron men are first choice. They should be alert, sober men, and should be paid higher wages than the rest, as upon their efficiency depends the excellence and progress of the work. The prospect of promotion which is thereby held out to the others promotes the industry and discipline of the entire force.

A small surfacing gang immediately follows the track-layers. Any scarcity of men at the front can be supplied from this gang, and any extra men at the front can at any time be profitably added to the surfacing gang.

1605. Locating Joint Ties.—The foreman should detail two trustworthy men to locate the joint ties. They carry a measuring pole of the standard rail length, usually 30 feet, and locate the joints by measuring from the ends of the fixed rails. They also complete the work of spacing the intervening ties, which can not be done until after the joint ties are placed.

TRACK JOINTS.

1606. There are two forms of rail joints in general use, viz., **suspended** and **supported.** Both forms have merits peculiar to themselves, but both are rarely found on the

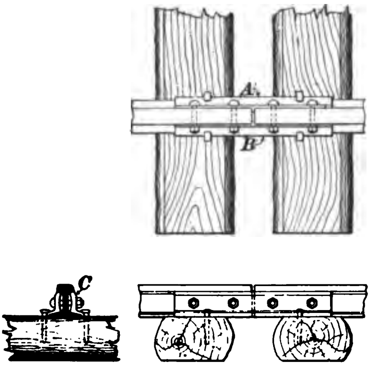


Fig. 489.

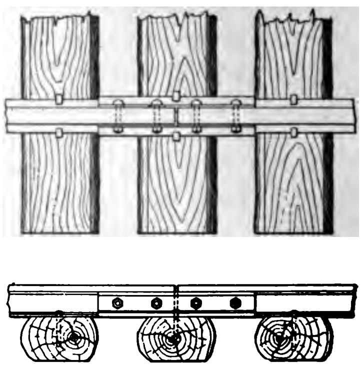


Fig. 490.

same road, either one or the other being used exclusively. A cut of a suspended joint is given in Fig. 489, and of a

supported joint in Fig. 490. In the *suspended joint* there are two joint ties spaced about 6 inches in the clear. The joint is spaced midway between the ties, which should be carefully selected, have broad faces, and be of uniform thickness throughout. In the *supported joint* the tie is placed directly under the joint. The angle splices *A* and *B*, which are shown in section at *C*, vary in length from 24 to 36 inches. Those 24 inches in length have 4 bolts, and those from 30 inches upwards have 6 bolts. A joint to be perfect should have the same strength as the rail itself, but such a joint has not yet been devised. A vast amount of time and money has been expended upon the development of rail fastenings. Iron chairs and fish-plates, once in universal use, have disappeared. The angle splice shown in section at *C*, Fig. 489, is generally accepted as the best rail fastening yet invented. The prerequisite of a good rail fastening is a strong shoulder which will closely fit under the head of the rail, and a broad base closely fitting the base of the rail and extending its entire width, reaching down so as to bear upon the tie. The plates do not fit closely to the web of the rail,

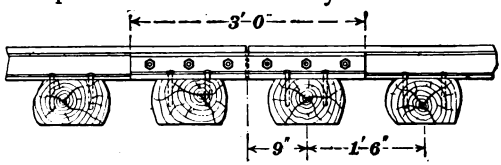


FIG. 491.

but are curved as shown in the section *C*. The holes in the plates as well as those in the rails are oblong so as to admit of the expansion and contraction of the rails due to changes of temperature.

Bolts should be of a size suited to the weight of the rail, though there is small danger of getting them too heavy. Track bolts are usually fitted with nut-locks of either metal or fiber. Trackmen should avoid straining the bolts when setting up the nuts. A half turn of the wrench after the nut has come to a bearing is sufficient. Though there are still some railroad men who strongly adhere to the supported joint, yet general experience has abundantly proved the

superiority of the suspended joint. The angle splice in general use on trunk lines is 3 feet in length, carries 6 bolts, and complete weighs from 40 to 60 pounds. The joint is suspended, and the ends of the splices also come midway between ties, as in Fig. 491.

The angle splices should be slotted and spikes driven through them into the tie to prevent the creeping of the rails. In the suspended joint there are two slots in each splice, as shown in Fig. 489, and in the supported joint but one.

Spike slots in the rails are not admissible, as they prevent the full expansion and contraction of the rails.

RAILS.

1607. Care in Unloading Steel.—Rails are often bent in consequence of careless handling. There is no excuse for either foremen or workmen for this. The rails are unfit for laying until straightened, but they are often laid in a bent state, giving a bad surface and line. The *surest* remedy is *proper handling*. The rails are always loaded properly at the rolling mill, and the kinks are put in them either in transfer or in delivering on the grade. When rails are to be transferred from one car to another, rails of suitable length should be used as skids upon which the rails to be transferred are pushed from one car to another. When from scarcity of flat cars, rails are shipped in box cars, rollers are placed in the end doors of the box car, and the rails are rolled as they are transferred. The rails should always be placed in regular order, as shown in Fig. 492.

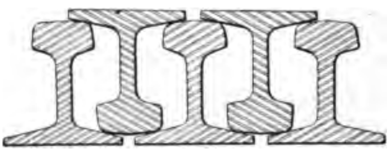


FIG. 492.

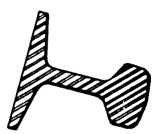


FIG. 493.

In unloading, there should be enough men to handle the rails with ease and dispatch. The rail should be lifted clear

of the car floor and carried to the edge of the car. All should be ready, and at the word, the rail dropped clear of the car so that it will fall in the position shown in Fig. 493, in which position the danger of kinking is entirely avoided. Other men should stand on the ground removing each rail as soon as it drops, so that one rail shall not fall on top of another. Rails must not be dropped from the cars on rock or loose stones, but on dirt, which will insure their safety.

None but the best men should be employed on the steel car. They should be strong physically, understand plain English thoroughly, and be prompt and active. When men, because of difference of nationality, fail to readily understand each other, confusion is sure and accident almost certain to follow. The same gang of men should handle all the steel. If the track laying is to be rushed, at least two, and better three, steel cars should be provided, which permits of one being constantly at the front. As soon as a load of steel is transferred from the flat car to the steel car, a team of horses should be hitched to it and the car hauled to the front. The steel men at the front, having unloaded their car, return with it until they meet the loaded car. They then lift their empty car from the rails to the side of the track, allowing the loaded car to pass. The steel men push the loaded car the balance of the way unless the grade is heavy enough to require a team.

Steel cars should be light and strong, and capable of carrying a heavy load. The car should be of such weight as to be readily handled by the steel crew. The wheel base should be 8 inches in width, so that the car may pass safely over rough and poorly gauged track.

1608. Straightening Rails.—If from any cause, rails should be bent, they should be carefully straightened

FIG. 494.

before being placed in the track. If kinked, i. e., bent laterally as shown in Fig. 494, they may be straightened by

nicking the flange of the rail with a cold chisel on the convex side of the rail at the point *A* where the bend is the sharpest. Then, laying the rail on its base, a few sharp blows with a sledge on the side of the head of the rail at the point *A* will remove the kink. Kinks may also be removed by means of a **rail bender** or **jim crow**, shown in Fig. 495. The jim crow consists of two heavy hooks

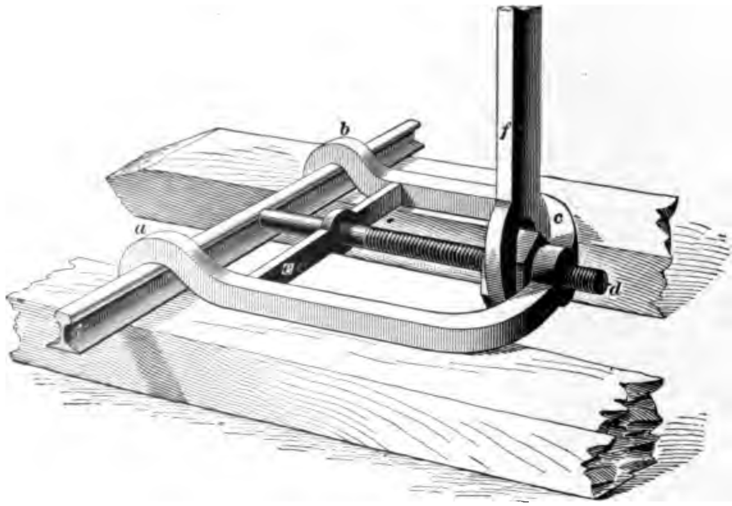


FIG. 495.

a and *b*, which fit over the head of the rail. The curved bar *c*, which unites these hooks, is drilled at its crown, and threaded to receive the screw *d*. The cross-bar *e* unites with the two hooks *a* and *b*, and serves as a guide to the screw *d*. Force is applied to the screw by means of the wrench *f*, having a long handle.

If surface-bent, as shown at *A* in Fig. 496, they are easiest

FIG. 496.

straightened with the jim crow. The straightening of the rails before laying will avail but little unless the ties are

well bedded, and all of the rails given a good bearing when the track is laid.

1609. Curved Rails.—Rails laid on curves should always be curved before being placed in the track. When laying track on new road, it is a much better policy to curve the rails in the material yard before forwarding to the track-layers. The material foreman should have a list of the curves in the same order in which they occur in the track. He should be able to determine the middle and quarter ordinates of a 30-ft. rail for any degree of curve, and should curve each rail accordingly. His list of curves will give the station of the P. C. and P. T. of each, from which he will determine the length of each curve and the number and length of rails required for each. These rails should be marked with the number of the degree of the curve for which they are intended, and the rails for each curve should be kept separate from the other rails by pieces of board, so as to prevent any confusion when they arrive at the front. One $29\frac{1}{2}$-foot rail is laid for each $6°$ of angle in the curve; hence, for a curve with a central angle of $30°$, the number of $29\frac{1}{2}$-ft. rails required is $\frac{30}{6} = 5$. In laying the track, the short rails should be equally distributed throughout the curve. The rails are curved either with a rail bender, shown in Fig. 495, or by the aid of a track lever and curving hook, shown in Fig. 497.

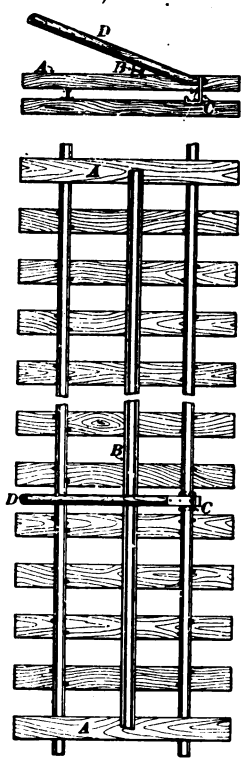


FIG. 497.

The latter process is as follows: A tie A is placed under each end of the rail B which is to be curved. A hook C is placed under the main track rail

between two ties, at about 6 feet from the end of the rail to be curved. The track lever D is then let into the hook C, and the men pry down upon the rail B, giving it the required curve. The quarter points should always be curved before the center, as it often happens that the center curves with the quarter points, thus saving time.

The practice of curving rails by dropping them across two ties, or pounding them with a sledge hammer, can not be too severely condemned. By the former method, an angle instead of a curve is often put in the rail, and sledging is liable to break a rail outright, or, at least, put a flaw in it which may result in actual fracture when laid in the track. Some of the worst accidents on record have been caused by broken rails, weakened by hard usage while being curved. The following table contains a list of curves and tangents and the number and lengths of rails required for each. With such a list, the material foreman can forward the rails curved and assorted. His facilities for curving rails should be of the best, and with a skilled gang of men he can turn off much more and better work than would be possible at the front:

MATERIAL FOREMAN'S LIST OF RAILS.

Station.	Deg. Curve.	Central Angle.	No. of 30-Ft. Rails Required.	No. of 29½-Ft. Rails Required.	Remarks.
40 + 90					End of track.
25 + 50	P. T.	43° 12′	29	7	
20 + 10	P. C. 8° L.				
530			35		
14 + 80	P. T.				
10 + 60	P. C. 6° R.	25° 12′	24	4	

1610. Assorting Rail Lengths.—Rails of different lengths should never be laid promiscuously. The short

rails should be piled by themselves in the supply yard and forwarded to the track-layers in such order and numbers as they may require. On curves, as the inner rail forms a smaller circle than the outer rail, it is sure to gain, and to maintain the joints in the same relative position, this gain must be compensated by the use of short rails. A list of the curves and the number of short rails required for each should be given to the supply foreman, whose business it is to forward the track material in the order named on the list. This table shows how the material foreman makes out his list.

EXPANSION AND CONTRACTION.

1611. In laying track, provision must be made for expansion and contraction of the rails, due to changes of temperature. As the temperature rises the rail lengthens, and unless sufficient space is left between the ends of the rails to allow for the expansion, the ends of the rails abut one against another with such force as to cause the rails to kink or buckle, marring the appearance of the track and rendering it unsafe for trains, especially those running at high speeds. If, on the other hand, too much space is left between the rails, the contraction or shortening of the rails due to severe cold may do equally great harm by shearing off the bolts from the splice bars, leaving the joints loose and unprotected. The coefficient of expansion, i. e., the amount of the change in the length of an iron bar due to an increase or decrease of 1° F. is taken at .00000686 per degree per unit of length.

EXAMPLE.—If an iron rod measures 30.015 ft. at a temperature of 90°, what is its normal length, assuming 60° as the normal temperature? The temperature of the bar must be $90° - 60° = 30°$ above the normal temperature.

SOLUTION.—As the increase in length is .00000686 ft. per degree for each foot in length of the bar, the total increase for 1 foot of the bar due to a rise of 30° in temperature is $.00000686 \times 30 = .0002058$ ft., and for 30 ft. the increase in length above the normal is $.0002058 \times 30 = .006174$ ft., or about $\frac{1}{16}$ of an inch. As the rail at a temperature of 90

measures 30.015 ft., of which length .00617 ft., say, .006 ft., is due to expansion, the normal length of the rail is 30.015 — .006 = 30.009 ft.

Ans.

To provide against the effects of expansion, an opening is left between the ends of the rails, and to provide against contraction, the holes in both rail and splice bar are made oblong, allowing about $\frac{1}{4}$ inch for extreme movement. The following *table of expansion* is a safe guide to track-layers for most latitudes in the temperate zones:

TABLE 31.

Temperature When Laying Track.	Space to be Left Between Ends of Rails.
At 90° above zero.....	$\frac{1}{16}$ of an inch.
At 70° above zero.....	$\frac{1}{8}$ of an inch.
At 50° above zero.....	$\frac{3}{16}$ of an inch.
At 30° above zero.....	$\frac{1}{4}$ of an inch.
At 10° above zero.....	$\frac{5}{16}$ of an inch.
At 10° below zero.....	$\frac{3}{8}$ of an inch.

To give to the track the proper opening at the joints, **expansion shims** are used. They are made of iron, and are of various forms. A simple and effective shim is made by bending a piece of $\frac{1}{8}$-inch iron into the form of a right angle, as shown in Fig. 498. This gives a combination shim of two thicknesses, viz., $\frac{1}{16}$ and $\frac{1}{8}$ inches. After the angle is formed, the $\frac{1}{16}$-inch shim is obtained by hammering the $\frac{1}{8}$-inch bar to the required thickness. The thickness of each shim should be clearly stamped upon it. When put in place, the shim reaches the full depth of the head of the rail, and the bent portion lies flat on the top of the rail. The shims should not be removed until the joint is

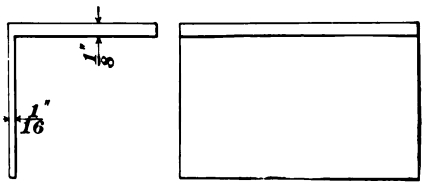


FIG. 498.

full bolted, and there should be a sufficient number of them on hand to keep the track-layers constantly employed, and not require them to wait until shims can be removed from bolted joints.

SPIKING RAILS.

1612. There is no part of the track laying more likely to suffer from carelessness than the spiking. A spike, to be driven properly, should be started in a really vertical position. The spikes at the joints, centers, and quarters of the rail should be driven first. The right-hand rail is usually spiked first. The gauge is then placed on the fixed rail, and the free one brought to the gauge and spiked.

The common and slovenly custom of driving spikes at an angle should not be tolerated. An almost equally pernicious custom is to drive the spike with the track at loose gauge and then bending the head so as to give the rails their proper gauge.

First see to it that the free rail is brought to the gauge. Then start the inside spike a little removed from the base of the rail, the head inclined slightly backwards. Having started the spike, a good blow will bring it to a vertical position, after which the blows should be delivered vertically upon the head. The last blow should slightly draw the head towards the rail base. Where the gauge is widened on curves, a special gauge should be provided and the eye not trusted to give the proper increase in gauge. Spikes should not be driven in the middle of the tie, especially in severe freezing weather, as they are liable to split it, but at from $2\frac{1}{2}$ to 3 inches from the outside of the tie, where the wood is sure to be sound and the grain less open.

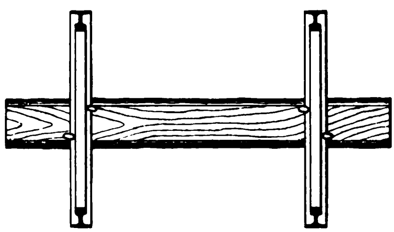


FIG. 499.

The proper arrangement of the spikes in the tie is shown in Fig. 499. Ties spiked in this fashion can not

become skewed, and the track, in consequence, thrown out of gauge.

In spiking, the tie must be held firmly against the base of the rail. If from any cause the rail does not lie directly

FIG. 500.

upon the tie, the tie must be held against the rail with a **nipping bar,** shown in Fig. 500.

The ends of the ties should be spaced at a uniform distance from the rail, both for the sake of appearance and to give to the rail a uniform foundation. A gauge made of hard wood and meeting this requirement is shown at *A* and *B* in Fig. 501.

The spiker first places the gauge upon the tie with its head close against the end of the tie, as shown at *A*. The

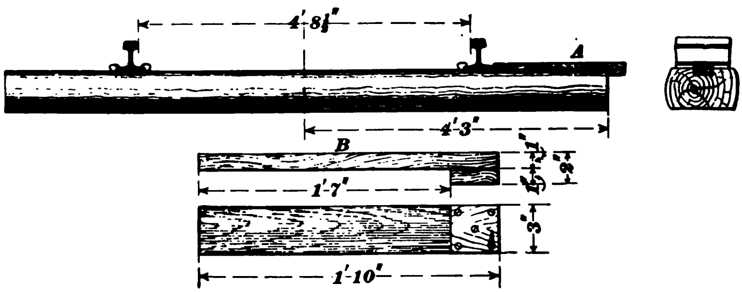


FIG. 501.

base of the rail is then brought against the end of the gauge and the inside spike started. The gauge is then removed and the outer spike started, and both driven home. The other rail being spiked to a proper gauge will make the rails equidistant from the ends of the ties. The gauging of the ties is too often done by guesswork, as is evinced by a ragged line.

1613. Spiking Bridge Ties.—Holes should be bored in bridge ties to receive the spikes instead of driving the

spikes directly into the tie. As bridge ties are sawed, they are often cross-grained and liable to split unless holes are bored for the spikes. The diameter of the spike holes should be about $\frac{1}{16}$ inch less than the diameter of the spike, so that, in driving, the hole will be completely filled with the fiber of the wood.

1614. Pulling Spikes.—When a spike is to be drawn from a tie in frosty weather, or from an oak tie at any time of year, it should always be given a light blow with a spike maul before using the claw bar. The blow breaks the hold which the wood has upon the spike, and permits of the spike being drawn with safety. Without this precaution the spike is liable to break off under the head. The instrument for drawing spikes is called a **claw bar,** and is shown in Fig. 502. Its weight is about 25 lb. The end *a* of the claw

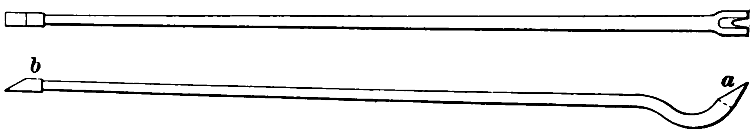


FIG. 502.

bar is divided like the claw of a carpenter's hammer and the bar bent into a *goose-neck* to increase the distance through which the opposite end *b* can move. In drawing a spike care should be taken that the claw is well under the spike-head before a strain is put upon the bar. When only the lip of the claw is under the head, there is great danger of the claw being broken, especially if a heavy stress is put upon it. When the spike is driven so deeply into the tie that the claw can not be forced under it, the end *b* of the claw bar, which is wedge-shaped, may be forced under the spike-head, lifting it so the claw may be used.

1615. Gauging Track.—In track laying, no part of the work should receive more careful attention than the gauging of the track. A **track gauge,** to be in proper position, must be at right angles to the center line of the

track, and with this fact in view the gauge shown in Fig. 503 was devised. The gauge consists of two U-shaped castings connected by a short iron pipe which is threaded at both ends, and screws into them. The castings have lugs on their under sides, as shown at *A* and *B*. The distance *A B* between the lugs determines the gauge. A line drawn across the faces of the gauge lugs is at right angles to a line drawn through the center of the iron pipe. To place the gauge at right angles to the center line of the track, bring both lugs shown at *C* against the head of the rail. A notch filed in the gauge at *D* marks the center of the track.

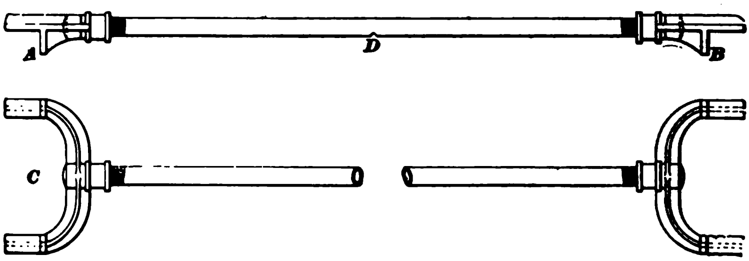


FIG. 503.

Never crowd the gauge in spiking the rails. Let the rails only touch the gauge marks. Place the gauge about eight inches ahead of the tie to be spiked. This places the gauge out of danger of the spiking hammers, and insures a perfect gauge.

SURFACING TRACK.

1616. As soon as the track is full bolted and spiked, it is put into surface. This is an easy matter where the ties have been bedded to grade, and requires much less material than where they have been placed upon the roadway and the rails spiked to them without any attempt at grade. If the track is to be earth ballasted, the material is taken from the shoulder of the roadway. If cinders, gravel, or broken stone is to serve as ballast, construction trains should furnish the material as fast as it is needed.

Ordinarily, earth is used on new lines, as the finances of

the company seldom warrant the ùse of costlier material. It is only on prairie lines that sufficient material can be borrowed from the roadway to put the track in permanent surface, but in most cases enough is available to place the track in safe condition for the full operation of the construction train.

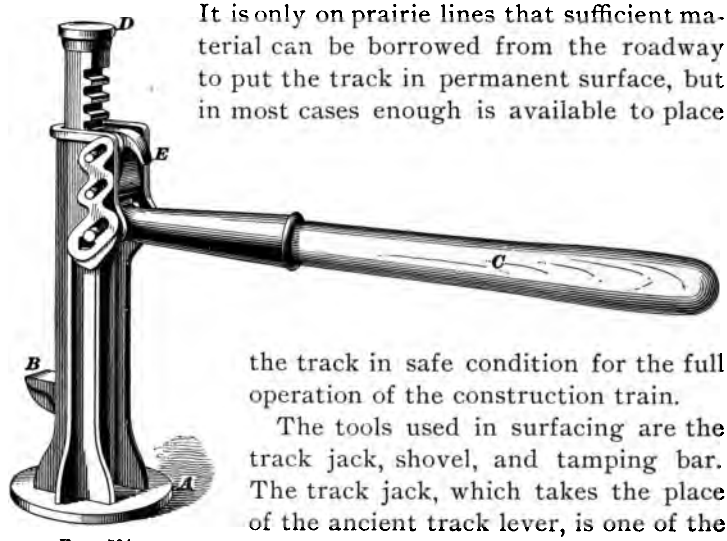


FIG. 504.

The tools used in surfacing are the track jack, shovel, and tamping bar. The track jack, which takes the place of the ancient track lever, is one of the most economical and indispensable of the trackman's tools. One of the best track jacks on the market is that made by Joyce, Gridland & Co., of Canton, Ohio, and is shown in Fig. 504.

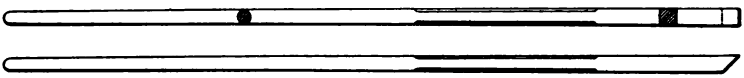
This jack is simply and strongly made. The foot *A* of the jack is placed between the ties with the lug *B* under the rail. By means of the lever *C* the toothed bar *D* is raised. The lug *B* forms a part of the bar *D*, the two forming one casting, and, consequently, in moving together, carry the rail with them. A tripper *E* is so arranged that if desired the bar *D* may be made to drop instantaneously. In using the jack it should always be placed on the outside of the rail with the lever pointing from the track. Numerous accidents have been caused by misplaced track jacks, some of them entailing great loss of life and property.

The track is raised to grade with the jack, and the material deposited with the shovel. Many trackmen use only the shovel blade in surfacing track for the first time, and this is probably the wiser policy, as the prime object of the first surfacing is to make the track safe for the

construction train, and any work which unnecessarily delays the construction train is manifestly unwise. There should be no confusion in the work as a result of changing work. Each man should be assigned to his special work and required to do it.

1617. Lining Track.—As soon as the track has a safe surface, it must be brought to line. This is done with lining bars, shown in Fig. 505.

In lining, the trackmen with bars are placed at the joints, quarters, and centers of the rails nearest a center stake.



Weight, 27½ lb.

FIG. 505.

The foreman places the gauge on the track at the center stake and orders the track thrown until the center mark on the gauge coincides with the tack in the center stake. He then moves his men to another center stake and repeats the operation. Having placed the track on center at the stakes for 300 or 400 feet, he lines in the intermediate portions by eye. He should then check the line at the center stakes to make sure that the track has not moved while lining the intermediate portions by eye. It is needless to say that if the ties have been laid to a tie line, the track will not require any lining until after the first surfacing.

1618. Final Surfacing.—After the construction train has run over the track for a few days, the track will show numerous low places, especially at the joints. A surfacing crew should then go over the line, putting the track in good surface. The material required for the final surfacing can be borrowed from the roadway or obtained by widening and ditching the cuts. That required for the track in the cuts is shoveled directly from the ditch into the track, while that required for the embankment should be hauled by the gravel train. This plan is in every way better than to borrow the material from the embankment.

The freezing and thawing of the following winter will cause the slopes of most cuts to break and cave, filling the ditches with heavy mud, which must be removed to make the track safe. Hence, the removal of this material for surfacing at the time of track laying is practically clear gain.

In the final surfacing, all ties should be thoroughly tamped. This is best done with the tamping bar shown in Fig. 506.

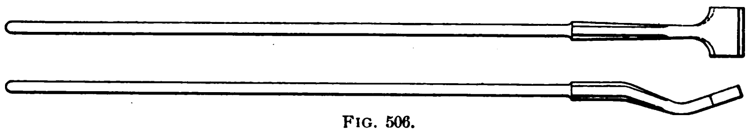


Fig. 506.

An excellent substitute for the tamping bar is the iron-handled shovel, which serves both purposes of the shovel and tamping bar. When using them, the foreman can spread out his forces, giving to each man his share of ties, and thus obtaining equal service from all. When the ties are to be hard tamped, the tamping bar is the tool for effective service. The ballast should be tamped under the tie, throughout the entire length, but hardest at the points directly under the rails, where the load is heaviest. In case the ballast midway between rails is tamped the hardest, there is danger of the ties being broken in two at the middle by a heavy train. This danger is especially great when the ties are of soft wood.

The object of ballasting track is not only to secure a firm foundation for the ties, but to so bed them that the track shall not be thrown out of line by the lateral thrust of passing trains. That mode of ballasting is best which most completely beds the ties and at the same time provides for the prompt removal of all water which falls upon the roadbed.

In filling in the track the material should be deposited in the middle of the track and not against the rails. It should be raised to a height of about $2\frac{1}{2}$ inches above the ties at their middle point *A* (see Fig. 507), and sloped towards the ends of the ties. Its surface at the inside line *B* of the rails should be such as to permit the shovel to be passed freely underneath the rail between the ties, and the slope

continued to the end of the tie where it should just meet the base of the tie. Outside of the ties, the shoulder $C\,D$ should continue at a slope of $1\frac{1}{2}$ inches to the foot to the edge of the embankment.

This insures complete drainage. Rain falling upon the roadway will run off before it can penetrate the ground.

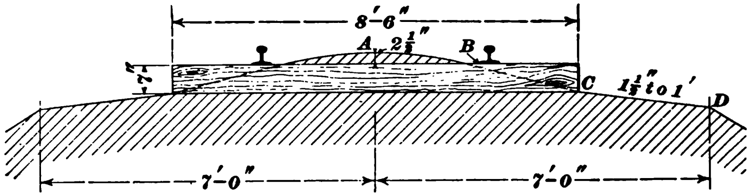


FIG. 507.

Provision must be made for conducting this surface water into natural channels. This is accomplished by means of *side ditches.*

DRAINAGE.

1619. Ditching and Ballasting.—All railroad managers and operators are united in their estimate of the importance of *thorough drainage.* This can be effected only by a thorough system of drains and ditches. These should be of such number and size that they will not only meet the requirements of an ordinary rainfall, but also of the *heaviest freshets.*

Ditches are of two kinds, viz., side ditches, those excavated in cuts on both sides of the roadway, and surface ditches, those excavated above the slope of cuts to prevent the slope from being washed down. Side ditches are partially made during the grading of the roadway; surface ditches should always be completed during construction, as they are of the first importance in affording protection to the slopes against the floods of surface water which invariably accompany a heavy freshet. The water which, during a heavy shower, falls upon the side slopes and track, is about all that ordinary side ditches can accommodate; and if the protection of surface ditches is lacking, great quantities of surface water are

discharged at different points directly upon the unprotected slopes, soaking the roadbed, carrying with it quantities of earth and gravel which choke the side ditches, and, where the quantity of water is sufficient, producing a washout. In fact, the surface ditch is indispensable to a newly constructed road, and the question of its construction should not be open to debate.

As stated above, the side ditches are partially made during the grading of the roadway, and their completion deferred until the ballasting and final surfacing of the track. All the material excavated in completing the ditching should be used in surfacing the track, and any additional material required should be obtained by widening the cuts.

Wet, springy cuts are a serious annoyance and expense to any railroad, especially where the widths of roadways and slopes are limited by a fixed standard. A cut whose width and slopes are ample for sand or gravel is totally inadequate for clay. Springs in the bottom of the cut keep it constantly wet, and a firm track is impossible. Frost and rain cause the slopes to cave, filling up the ditches and often covering the ties from sight. Such a track will be full of sags in summer and badly heaved in winter, and at no time safe for trains at high speed. There is nothing to be gained from tinkering with and patching up such a track. The permanent cure is in widening the cut and reducing the slopes, so that whatever material caves in will lodge well outside the ditch line. The ditches should be from 8 to 10 feet from the rails, and so deep that the ballast will not be soaked by the water flowing through them. The cost of such work will often be heavy, but it will end the trouble and prevent the further wasting of money in useless tinkering.

During the construction of the road, the *slopes* and *width of roadway* should, so far as possible, be *suited to the character of the material* in which the excavations are made.

The dotted lines in Fig. 508 show a standard section of a through cut as made during the grading of the line, and the full lines show the section after the track has been laid, the cut widened, the ditches made, and the track ballasted. The

material excavated in this work is used for ballasting the track. In establishing the grades for a new line, the competent engineer will make provision for the drainage of the cuts. Sometimes the grade is continuous throughout the cut, carrying all the water one way; but where the average grade is level, the drainage is effected by making the grade to ascend from both ends of the cut, uniting them by an easy vertical curve at the middle.

Where the cut is short, it is a mistake to break the gradient, but rather depend for drainage upon well-constructed ditches. Where the grade of the cut is level, the ditches at the middle of the cut are made shallow, and the depth gradually increased towards the ends. The grades of such ditches should

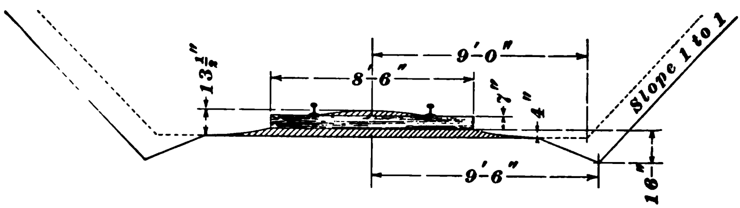


FIG. 508.

be given by the engineer, and the excavation made to conform to those grades. It is the continuous grade which gives to a ditch its full efficiency. Where the grade is a sucsession of levels and sudden drops, the level places accumulate mud on account of a sluggish current, and the steep places wash badly because of a rapid current; and in a comparatively short time a new ditch must be made.

Particular attention should also be paid to the alinement of the ditch. Crooks in the ditch impede the flow of the water and tend to increase the deposit of mud. First determine the line of the ditch, with a view of avoiding any unnecessary excavation, and then cut the ditch to a true line.

When *gravel* or *broken stone* is used for ballast, the section of the roadbed is somewhat altered, although its general dimensions remain the same. As stated in Art. **1603,** the ties should not be bedded when cinders, gravel, or stone

ballast is to be used. A section of roadway ballasted with either cinders or gravel is shown in Fig. 509. The ballast is filled in between the ties, flush with their tops, and extends to a depth of 8 inches below them, sloping from the outer top edge *A* of the tie to the edge of the ditch.

On some roads the shoulders at *B* and *C* are rounded off, as shown by the line *D E*, before the ballast is deposited. The effect of this is to improve the drainage.

The ditch extends 12 inches in depth below *subgrade;* i. e., the line *B C*.

The **subgrade** is the grade line laid down by the engineers for the grading of the roadway, and marks the bot-

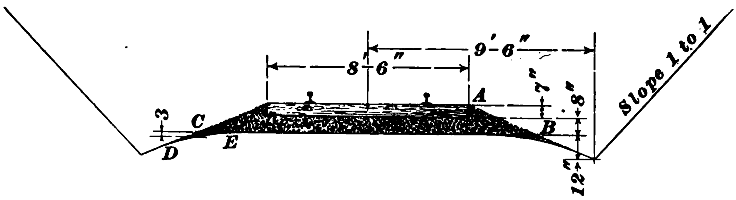


FIG. 509.

toms of cuts and the tops of embankments. The actual *grade line* marks the elevation of the top of the rail, and is from 15 to 24 inches above subgrade. When gravel or broken stone is used as ballast, the material excavated in ditching the cuts should be loaded on a gravel train and deposited upon the embankments wherever needed. The more

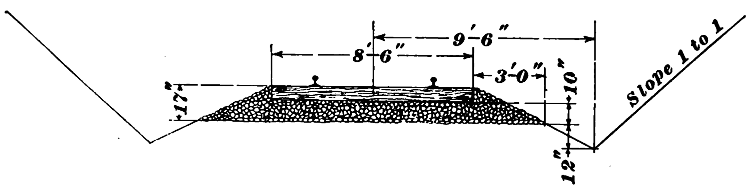


FIG. 510.

material deposited on the embankments the better, as they are bound to cave more or less from the effects of frost and rain, before grass has grown in sufficient quantities to protect them.

A section of track ballasted with broken stone is shown in

Fig. 510. The ballast extends from 10 inches below the bottom of the ties to the level of their tops, and is shouldered outwards from the ends of the ties as shown in the figure. The side ditches are 12 inches in depth, the slope of the ballast and that of the ditch forming practically a straight line. The slopes of the cuts given in Fig. 510, as well as those given in Figs. 508 and 509, are 1 horizontal to 1 vertical This is the steepest slope at which earth will stand. The certain effect of weather is to cause the slope to cave, flattening it and at the same time filling up the ditches. In all recent railroad construction, where the finances of the company will permit, the slopes of both cuts and embankments are made the same, viz., 1½ horizontal to 1 vertical. Cuts can be widened much more cheaply before than after track-laying, but it is often a difficult question to decide *where it is safest to economize.*

The proper time to clean ditches is in the fall, commencing about October 1 and finishing by or before November 1. Occasionally the slopes of a cut cave in so badly that ditches require frequent clearing. The only permanent cure is to widen the cut to such an extent that caving material can not encroach upon the ditches and track. Some writers on track insist that there should be no side ditch nearer than 10 feet from the rails, nor slopes less than 1½ horizontal to 1 vertical. This would require a roadway at least twenty-four feet in width for a single track, and involve an outlay which would prohibit the building of nearly all new lines.

The roadway and track sections given in the preceding pages are entirely consistent with moderate expense and thorough construction. When the line is fully equipped, traffic connections established, and business on a paying basis, there will be ample time for betterments and a prospect of money with which to pay for them.

The purpose of all ditches and drains is to convey the water to natural channels and thence out of reach of the track. In Arts. **1461** and **1467**, mention was made of the common fault of making culvert openings too small.

They should be designed to meet the requirements of the severest storms and freshets. At all low places where the water remains standing alongside the track, open culverts should be built, allowing the free passage of the water. Brooks liable to overflow and wash the track should have their channels deepened or their banks raised. After every freshet, all water passages should be thoroughly examined and all obstructions, such as sticks, brushwood, weeds, etc., removed. Brush and weeds not only obstruct the passage of water, but, when dry, are easily ignited by sparks from the engine and are a continual menace to the safety of the track.

Open passages for water, built of framed timber, are to be condemned. They are likely to be undermined by a freshet, and are at best a cause for anxiety. If stone is not available, the track should be carried on piles. The bents of piles next the embankment should be sheathed up with plank to prevent the washing of the embankment.

1620. Side Tracks.—The opinion still prevails on some roads that any kind of work or material will answer for a side track. This is entirely wrong. The same skill, work, and materials that go into the main track should be expended upon all side tracks. The tax upon trainmen and rolling stock is always greater on side tracks than on the main line, and it is there that time is either saved or lost. With a good track, shippers can move a loaded car with a team; whereas, if the track is rough, they are compelled to wait for a freight train, which must stop until the car can be shifted. It is admissible to use No. 2 ties in a side track, except that all joint ties should be strictly first-class. Where No. 2 ties are used they should be placed closer together in the track, so as to insure a first-class foundation for the rails. All side tracks should, as far as possible, have a switch at both ends. This permits trains to enter the side track from both directions without passing a switch and backing into the siding; it also effects a saving of time, labor, and fuel.

CARE AND MAINTENANCE OF TRACK.

SPRING TRACK WORK.

1621. At the first break up of winter the spring track work begins. The section foreman should plan his work so as to take advantage of each day as the season advances. As soon as the snow has disappeared from the track, which will always be a few days earlier than from less exposed places, he should set his men to work at cleaning up the station grounds and yard. All scattering track material should be collected and neatly piled at a place convenient to the hand-car house. All rubbish which may have accumulated during the winter must be removed and used either to fill up low places in the right of way, or burned, if necessary.

All switches should be thoroughly repaired and put in perfect line. Battered rails should be replaced by good ones; guard-rails and frogs examined and defects in them remedied, and all ties collected, loaded on cars, and distributed along the section, where they will be ready at hand when needed to put in the track. All breaks in fences should be repaired at the earliest opportunity. The approaches to highway crossings should be made safe, and everything done in the way of repairs which the season will permit of. As the frost begins to leave the track, settlement commences, and the track should be carefully watched, thick shims being replaced by thinner ones as the settlement goes on, and all shims removed as soon as it is possible to spike the rails to their proper surface.

Every joint throughout the section should be examined; all loose bolts tightened; nut-locks or washers supplied where needed, and broken bolts replaced by new ones. As the frost leaves the track, especially in wet cuts, soft places will appear. These must be reported to the train dispatcher at once. By keeping the side ditches clear and deepening them as the frost leaves the ground, soft places can usually be made safe until the ground settles, when thorough repairs should be made. If the place becomes dangerous the fact

must be reported by telegraph to the roadmaster, who will furnish the necessary men and materials to make the track safe.

1622. Washouts.—The melting snow together with the spring rains greatly increase the volume of surface water, and as the frost comes out of the ground but slowly, ditches and natural water channels are taxed to their utmost capacity. It is at this season of the year that washouts and landslides are chiefly to be feared. All ditches, culverts, and bridges must be kept clear of obstructions, and the track watched night and day so long as danger is to be apprehended. In case of a severe storm, the section foreman should send a responsible man to one end of the section with the proper signals to stop trains in case of danger, while he goes to the other end of the section, leaving a man to guard any dangerous spot until the section is entirely covered. In case he lacks the means to repair any damage done, he must report the fact by telegraph to both the train dispatcher and roadmaster, in order that the former may hold trains at convenient points while the latter can rush a construction train through to the point of danger. The foreman should include in his report the location of the break or washout, the number of the bridge or culvert, the length of the break, the number of missing bents, and any information which will aid the roadmaster in making a correct estimate of the men and materials necessary to repair the damage. He can then set to work with his men, making such repairs as his limited force will permit of, and being ready to render every assistance in his power to the roadmaster, who assumes charge on his arrival. A foreman should never attempt any repairs of track until he has inspected his entire section, as two or more breaks may occur simultaneously, and while repairing one break an accident is liable to occur at another.

1623. Repairs of Track.—As soon as the frost has left the track and all shims have been removed, bringing the rails down to the surface of the ties, the section foreman should go rapidly over his section, making such repairs as will render the track safe and reasonably smooth. If the

track is well ballasted with gravel or broken stone these repairs will be quickly made, as such track will hold a good line and surface after the severest winter. If, however, the ballast is clay, the track will show many low places and an uneven line. The track jack, shovels, and picks are all the tools needed for the first repairs. A man is set to dig block holes for the jack at the lowest points in the sags. The track is then raised until it is in average surface with the track at either end of the sag. Dirt is then shoveled under the ties, care being taken to throw it well back to the middle of the tie. No attempt should be made to tamp the ties other than to fill up the cavities formed by raising them. A part of the force will follow, dressing up the track and filling block holes. The foreman should stop raising track about two hours before quitting time, taking with him sufficient hands to line up and gauge the track surfaced during the day. The *line side* of the track is then given a perfect line. Either rail may be taken as the line side, but the same rail should always be used for lining. A part of the force take the gauge and spike maul and spike the track to gauge, while the rest follow, dressing up the track. This work will put the track in perfect line and fair surface, and by the time the entire section is covered the ground will be thoroughly settled and the track in shape for permanent surfacing.

1624. Lining Track.—When lining track the foreman should stand with his back to the sun and as far from the piece of track which he is to line up as his eyesight will permit. This gives him a better view of the straight portions on each side of the crooked portion, all three of which are to be brought into the same straight line. A simple device, much practiced by trackmen when lining track, is to place small lumps of dirt on the top of the rail to be straightened. These lumps show plainly in contrast to the bright, unbroken surface of the rail, and when brought into range insure a good line.

With a strong section gang the foreman can readily perform any of the tasks which confront him; but when from

necessity his force is reduced to a minimum, he is obliged to resort to every expedient within his knowledge. He must not only direct the work, but lead in its execution. Frequently a foreman will have charge of ten miles of track, and have but four hands besides himself wherewith to maintain it. It is under such circumstances that ingenuity and energy count at their full value.

When a sag in the track has caused a crook in the line, and there is not sufficient force to throw the track to line, the following scheme will enable the foreman to straighten the track and hold it in place. He can only straighten one rail length at a time, and to do that he should remove the spikes from three or four of the ties under the rail. The ties so detached from the rail are called **dead ties.** The lining bars are then placed under the rail upon the dead ties, which afford a far firmer foundation and leverage than ordinary ground. The track is then thrown to line, after which the dead ties are shifted to their proper position. If the track has a tendency to slip back out of the line, the rails can be temporarily spiked to the dead ties, which, being securely bedded, will hold the rails permanently in place.

1625. Straining of Track Bolts.—Reference has already been made to this serious fault, which is almost universal among trackmen and generally due to ignorance on their part. The rail splices on most American roads are fitted with nut locks of either metal or fiber, the object of which is to lock the nut and at the same time permit of the expansion and contraction of the rail. In order that expansion and contraction may take place, the nut should only be brought to a snug bearing on the nut-lock, whereas, the common practice is to screw on the nuts as far as the strength of the trackman will permit. This places the bolt, nut-lock, and nut under a severe strain, with the result that the rail can not freely expand and contract; the nut-lock is deprived of all power to act, and at the first abrupt change of temperature the nuts are liable to snap off on account of the sudden strain. One of the first duties of the section foreman is to explain to his men the object of the slots in the

rails, expansion shims, and nut-locks. In putting in track bolts, first bring the nut to a bearing, after which a half turn with the wrench is sufficient. Track wrenches should not be longer than 16 inches for ¾-inch bolts. Spike slots should always be made in the angle splice. These prevent the creeping of the rails and at the same time permit the free expansion and contraction of the rails.

1626. Removing Old Track Bolts.—In removing old track bolts they should never be battered with either hammer or wrench. The nut should not be entirely removed from the bolt until the bolt is loosened in the splice. When the nut is nearly off the bolt, give it a slight tap with the track wrench. This will loosen the bolt without injuring the thread. The thread of the old bolts should be oiled and the nuts well screwed on so that they will be complete and in readiness for service when needed.

1627. Loose Track Bolts.—Changes of temperature often cause the loosening of track bolts. These are most noticeable in the spring and fall of the year. Trackmen should watch for and promptly tighten all loose track bolts, as they are one of the main causes of low joints.

1628. Line and Surface of Bridge Approaches.—Special care should be taken to make the line and surface of the track on bridge approaches as nearly perfect as possible. Pile bridges are liable to heave, especially when the ice surrounding them is lifted by a spring freshet. Section men should not attempt to repair bridges unless circumstances require it. They have neither the experience nor tools for such work.

Bank sills (those resting upon the embankment and supporting bridge stringers) are continually settling, and cause a bump, or lift, in the track at the bridge line. The sills should be raised and kept in perfect surface by hard tamping, and all bank ties kept well tamped. If possible, avoid placing a rail joint over a bank sill. It is almost certain to be low at times; but rather arrange the track so as to bring the center of the rail at that point.

SUMMER TRACK WORK.

1629. General Repairs.—On Northern railroads, general track work commences with the month of May. By that time all frost has left the track and settlement has taken place generally.

The section foreman should go to the end of his section to commence track repairs, and work towards home, finishing as he goes, raising all small sags and low joints to a proper surface, tightening all loose bolts, relining the track, and correcting all defects in gauge. He should fill in the middle of the track and dress it down to the track shoulder. He should allow nothing short of actual compulsion to call him from his work until the entire section is covered. He will then be in readiness to put in new ties, lay new steel, surface track, or cut weeds according as the work demands. In going over the track, the foreman can correctly estimate the number of new ties needed and make early requisition for them in order that they may be on hand when needed. He should keep a record of the places where new ties are needed and distribute them accordingly.

1630. Track Ties.—Track ties constitute one of the most important items in the initial cost and maintenance of a railroad. The company should provide the best ties within their means, and, if possible, have them well seasoned before being placed in the track. Ties made from logs split in two parts should be laid with the sap side up. This brings the wide or heart side of the tie underneath, which is the position it would naturally take. Pole ties, those made from young trees, are more lasting than those made from large logs, as the older the tree, the more open and brittle the timber. Sawed ties are usually smaller than hewn ties. They are also often cross-grained, and hence more easily broken. Tie specifications should always require uniformity in length and thickness and the removal of all bark. Tie inspectors should strictly enforce these specifications. Tie contractors are quick to note any

laxness in the enforcement of specifications and always ready to take advantage of it.

Ties in the roadbed should be not less than 8 feet in length, 7 inches in thickness, and show at least 7 inches of face and be hewn to a uniform thickness throughout their entire length. Winding ties should be promptly rejected. They are dear as a gift.

The life of a tie depends not only upon the kind and quality of its timber, but also upon the weight of the rails, condition of the roadbed, and much upon the climate. In Northern latitudes, decay is almost entirely suspended during the late fall and winter months, while in Southern latitudes decay goes on almost uninterruptedly throughout the year. The yellow pine ties of the South are best fitted to withstand the effects of the climate, and when of sound heart timber they are fairly lasting.

The loss sustained from the use of inferior ties is apparent when one considers the cost of repairs and renewals. A track laid on ties with an average life of 8 years, and costing 60 cents each, is vastly more economical than a track laid on ties with an average life of 5 years and costing 40 cents each. The track laid on the more expensive ties will be superior from the start to that laid on cheaper ones, and, besides requiring far less repairs, it will be in good condition when the cheap track must be entirely rebuilt. The breakage of spikes and angle splices is much greater where cheap ties are used, and accidents more frequent and severe.

1631. Placing New Ties in Track.—When renewing ties, no more material should be removed from the track than is necessary to allow the new tie to go into its proper place. Where the track is mud ballasted, remove the dirt from the sides and from the ends of the tie to a depth a little below its bed, but without disturbing the bed of the old tie. If two ties side by side need renewal, a single trench between them will serve for removing both. Remove the spikes and spring the rail up from adjoining ties, slipping a spike under it. Then knock an old tie into

the trench and pull it out. Pull the new tie into the trench from the opposite side of the track and have two men slide it into place, keeping it well up against the rail until it is in place. If the track is low, throw some fine dirt under the tie and spike the tie to the rail. The ballast removed in putting in additional ties should be thrown into the trenches made when removing the first ties. When all the rotten ties are removed from one rail length, fill in and dress the track before beginning on another rail length. If, after the ties are in place, the track proves to be a trifle high, the defect will disappear after the passage of a loaded train. This method of putting in new ties does away with most of the labor of tamping, and the work is better done. A gang can put in from one-quarter to one-third more ties in this way than by any other method, but it is restricted to a *mud-ballasted* track alone. If the ballast is gravel or broken stone, all new ties must be tamped. The tie must be held up against the rail with a bar while it is spiked, and the ballast thoroughly tamped with a tamping bar. All new ties must be placed square across the track, and if the old ones are too widely spaced, additional ties must be put in the track with selected ones at the joints. Never spring the rails off the ties on stone or gravel-ballasted tracks, as the ballast collects under the base of the rail and prevents its proper bearing upon the ties.

The prime object of track repairs is to make the track safe, and if some parts of the section are more needy than others, the foreman should first make those places safe and then go ahead with continuous repairs.

1632. Estimating New Ties for Repairs.—The proper time for estimating the number of new ties needed for repairs is in the fall of the year. In the Northern States the winter is the proper season for manufacturing ties, and most tie contracts are let in that season. If the estimates are made up and sent in to the roadmaster in the fall, he can make more favorable contracts and be sure of having a supply when needed.

In making his estimate, the foreman should walk over his entire section, testing every tie of which he is in doubt and reporting the actual number needed, and no more. The renewing of ties is one of the great items of cost in the maintenance of a railroad, and a careful foreman can do much towards prolonging their life.

1633. Disposition of Old Ties.—All labor spent in handling old ties is unremunerative, but they must be disposed of. In sections where timber is scarce they can usually be sold for fuel. If, however, fuel is abundant and cheap, the best way to dispose of them is to burn them.

1634. Tie Account.—The foreman should keep an accurate tie account, which will show at once the number of *ties received*, *put in the track*, and *on hand*. The following is a good form for tie accounts:

TIE ACCOUNT FOR ONE YEAR.

Months.	Ties Received.		Ties Put in Track.		Ties on Hand.	
	Hard Ties.	Soft Ties.	Hard Ties.	Soft Ties.	Hard Ties.	Soft Ties.
January	......	......	......	......	......	......
February	1,000	400	......	......	1,000	400
March	800	300	......	......	1,800	700
April	......	......	400	100	1,400	600
May	......	......	600	400	800	200
June	......	......	800	200	......	......
July	......	......	......	......	......	......
August	......	......	......	......	......	......
September	......	......	......	......	......	......
October	......	......	......	......	......	......
November	......	......	......	......	......	......
December	......	......	......	......	......	......

1635. Cutting Weeds.—On all mud-ballasted roads the cutting of weeds is an important item in the cost of track repairs. All weeds within a distance of $3\frac{1}{2}$ feet from the rail should be kept cut clean to the surface of the ground. It is important to prevent their getting an early start; hence, when making track repairs early in the spring the surface of the ground should be shaved over either with a shovel or weed cutter. This will increase the labor of early track repairs, but it will save much subsequent labor and loss of time.

A heavy growth of weeds seriously checks the speed and efficiency of a train, especially on heavy grades, besides

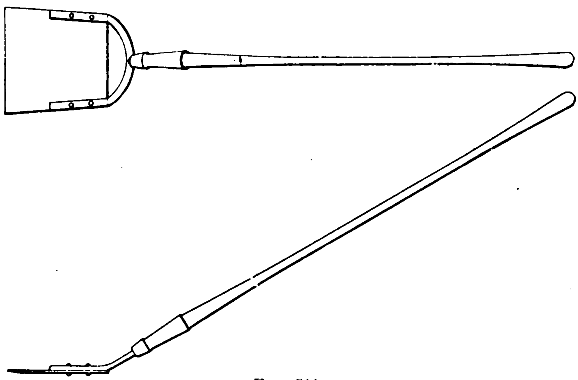


FIG. 511.

promoting decay of ties. For cutting weeds the blades of shovels or weed cutters should be ground to an edge, and a file kept handy for resharpening. The men should be distributed one to each rail length to prevent crowding and insure an equal share of work from each.

The weed cutter shown in Fig. 511 does more effective work, and is less severe upon the men than the shovel.

The handle of the weed cutter is considerably longer and the blade lighter than that of the ordinary track shovel. In using the weed cutter, men are not compelled to keep their backs continually bent as when using the shovel, and they can cover from one-sixth to one-fourth more ground in a day.

1636. Mowing Weeds, Grass, and Brush.—If the section force will admit of it, all weeds, grass, and brush should be cut from the right of way. This work should be commenced by July 20th, mowing first the grass and weeds about all wooden structures and burning them as soon as they are dry enough. This forms a barrier against fire, and insures the safety of these structures while burning other brush or weeds along the right of way. If possible, mow the entire right of way, burning the grass and brush as fast as they are dry enough. With the right of way clear of combustible matter there is comparatively small danger of fire being communicated to adjoining property. This assurance is well worth the cost of the work, and it is well known that by keeping the right of way clear of weeds and brush, grass is induced to grow, which is far easier to keep in order than brush or weeds.

WORK ON OLD TRACK.

1637. Combination Ballast.—A track can be better ballasted with a combination of stone and gravel than with either of these materials separately. Each material has advantages peculiar to itself. Stone is more solid, more open, and heavier than gravel, and, hence, better suited to form the foundation of the track where solidity and drainage are of first importance. Gravel is more abundant, more elastic, and much easier handled than stone. It does not wear the ties, rails, and rolling stock like stone, and is comparatively free from weeds, and, hence, is well suited to form the top course of ballast. Where stone is used only for the foundation of the ballast, it need not be broken so finely as when composing the entire roadbed.

Two carloads of gravel to a 30-foot rail length will make a first-class track where there is a foundation of stone 12 inches in depth.

1638. Preparing Old Track for Ballasting.—When old track is to be newly ballasted with stone, gravel, or cinders, all dirt should be removed from between and from the ends of the ties down to the base of ties and placed on

the shoulder of the roadbed. This will considerably strengthen the roadbed and afford a support to the ballast.

The engineer should set grade stakes 50 feet apart, giving the elevation of top of rail for the finished track. Where sags occur, if it is intended to fill them, the material necessary for raising the track should be delivered, and the track raised to the required grade before the ballasting is begun.

1639. Reserve the Best Ballast for Cuts.—When *gravel* is the best available ballast, and that of inferior quality, select the cleanest gravel for the cuts, where drainage is most difficult and the track most affected by the frost. All mud ballast removed from the roadbed in cuts should be deposited upon the adjacent embankments, which are constantly being reduced in width by the action of rain and frost. If the ballast is a mixture of gravel, sand, and loam, it should be raised a full 3 inches above the tie at the center of the track and carried out flush with the tops of the ends of the ties. All gravel beds contain streaks of clear gravel. With a little care and calculation the clean gravel can be loaded on separate cars and the train made up with the selected cars by themselves. The inferior ballast should be unloaded on the embankment and the selected ballast deposited in the adjacent cuts. Make the track shoulders of equal weight. Track with unequal shoulders is sure to work out of line.

Embankments should be made at least 14 feet in width at the top before depositing the gravel ballast, and 16 feet in width if the means of the company will permit. With a 16-foot embankment there is no loss of ballast from its being crowded over the shoulder.

1640. Ballast Required for a Mile of Track.—Allowing an average length of 33 feet per car, 160 cars will cover 1 mile of track. If the trains average 8 cubic yards per car, they will form a continuous bed 12½ feet in width at bottom, 12 feet in width at top, and 6 inches in thickness. Of this amount it will require about one-half to fill in between the ties and dress the middle of the track. This will leave

a bed of 3 inches beneath the ties. By unloading two cars in a place, the depth of the ballast under the ties is increased to $8\frac{1}{2}$ inches, which will make a first-class track, providing the subgrade is compact and thoroughly drained.

Gravel may be loaded at the pit for 75 cents per car, making the cost per mile, 2 cars to a rail length, about $250. Under favorable conditions, gravel can be loaded with a steam excavator for considerably less than the above figures.

1641. Gravel Pits.—The cost of loading gravel at the pit depends largely upon the manner in which the excavation is conducted. The prerequisite for cheap loading is a long, high, and regular working face. In laying out a track to a gravel pit, the ground should be well considered and the track placed so as to meet the above conditions for loading. The switch should be so placed that the turn-out curve is passed before the gravel pit is reached. If the face of the gravel bed is uneven at the start, commence loading at the projecting points and continue until the face is uniform. With each movement of the track, excavate deeper if the depth of the gravel will permit, and so increase the height of the working face. Gravel is generally overlaid with a layer of earth. This earth mixes with the gravel in loading, and the proportion of earth grows less as the height of the working face increases. The grade of the track should be made as uniform as possible, and the track maintained in such order that an engine may draw a full train load from the pit. Under fair conditions, 10 loaded cars constitute a train. If a steam excavator is being used, there should be enough cars on hand to keep the machine constantly employed. The empty cars should be placed on a spur track, connecting with the track leading to the pit, and shifted by teams as they are needed. When a train of empty cars is returned to the pit, the cars are switched to the spur track, and the loaded train hauled out.

1642. Raising Track.—When raising a track to a surface, the following method is recommended: Take a piece of board 1 by 4 inches and 5 feet in length. Cut two

notches, each 3 inches deep, to fit over the rails, the space between the notches being equal to the gauge of the track. Place this *sighting board* at a high place in the track, from 8 to 10 rail lengths ahead of the point where you intend to commence track raising. Shim up the sighting board to a perfect level, giving it the same height to which the top of the rail is to be brought in the raising. Then, go to the point where you intend to commence track raising and lift the track to a proper height, bringing both rails to the same level. The spirit level is then laid aside and the intervening track brought to a surface by *sighting*. When sighting, stand from 50 to 75 feet from the track being raised. Raise and tamp each joint about $\frac{1}{4}$ inch higher than the actual surface. In raising, two jacks, a heavy and a light one, should be used, the heavy one to raise the joints, and the light one to raise the centers of the rails. Do not attempt to raise a rail center until the jack is in place at the next joint, and then raise together. This prevents the springing of the rails and insures a smooth surface.

By sighting in the rails, a more uniform surface is obtained, and the delay occasioned by the repeated use of the spirit level is avoided. When the sighting board is reached, it is removed, and the track brought up to the proper surface by sighting.

In sighting in a curved track, sight along the inside of the rails. This permits of longer and better sights. The foreman should know the time when each regular train is due, and have the track safe for its passage. This is accomplished by a *run off*, extending from the new to the old surface. This should be 30 feet in length for each 6 inches of difference of elevation between the old and new track surface.

The amount and quality of work done will depend much upon the organization of the force. A good foreman will soon learn the good points of his men and distribute them accordingly. A gang of 14 or 16 men should be distributed as follows: Two with jacks; two to tamp the ends of the ties; four to tamp the centers, and the remaining men

equally divided, one-half to be employed in filling in ahead of the tampers and the other half in dressing up the track behind them. By dividing up the men equally, placing one-half the force on each side of the track, competition, both in amount and quality of work, naturally follows. With such an organization, a foreman can effectively employ a force within comparatively small limits, enabling him to give thorough inspection to all work, and to give directions wherever needed.

In raising track, both sides should be lifted together. The common custom of raising and tamping one side of the track at a time should not be permitted, as ties can not be given a uniform bearing.

The centers of track ties should not be hard tamped. The greater part of the train load comes upon the ends of the ties, and if their centers are hard tamped there is great danger of the ties being broken, especially if they are sawed ties. The ties should be hard tamped only 18 inches inside the rails. This will insure a firm bed and prevent all danger of breaking.

Uniformity of work is the secret of a smooth track, and the more alike the men work, the better will be the results.

1643. Yard Work.—All yard tracks should be uniformly surfaced throughout their entire length. The grade for all yard tracks should be given by the company's engineer, and should practically conform to that of the main line. If possible, yard tracks should be level. Cars are then much more manageable and easier handled. Where the yard and main tracks are of the same level, the main line should be put in perfect surface first. The adjoining yard track may then be given an equal height by a level and straight-edge. In the same way, any number of side tracks can be brought to the level of the main track. It is, however, much the better practice to have all elevations given with an instrument.

1644. Gravel as a Destroyer of Weeds.—One of the great advantages of gravel ballast is the saving in the

cost of weed cutting. Although ballasting with gravel is a heavy initial expense, the outlay ceases when the work is complete. Weed cutting, on the other hand, is a constant and heavy expense, and one of the great arguments in favor of gravel ballast is that gravel discourages the growth of weeds and thereby saves to the company a large annual expense. A railroad company should commence ballasting with gravel at the earliest possible moment, even though it is done in a fragmentary way, as every rail length of gravel is clear gain.

1645. A Day's Work.—Two rail lengths, or .60 feet of finished track, ballasted and dressed, per man, is considered a fair day's work. Foremen should stop raising track long enough before quitting time to line up, fill in, and dress all the track raised during the day. Track left without the ties being filled in and the shoulders properly dressed is easily thrown out of line. A heavy shower falling upon track which has not been properly filled in and dressed is certain to do great injury. In all cases, track should be left in a finished condition.

FALL TRACK WORK.

1646. Importance of Fall Work.—On Northern railroads, the prime object of *fall* track work is to prepare for the ensuing winter. One day's work in the fall expended in intelligent track work is worth an entire week of repairs in winter. The section foreman should lay out his work according to the needs of his section, and, as far as possible, adhere to his program.

1647. Surfacing and Lining Track.—The most important part of the fall work is the surfacing and lining of track. In addition, the track must be put in perfect gauge and dressed down.

In dressing the track, give as much strength to the shoulders as the available material will permit. With drainage provided for, the heavier the shoulder, the longer the track will hold its line and withstand frost.

1648. Seeding and Repairing Embankments.—It is the severe frosts of winter, followed by heavy spring and summer rains, which destroy embankments. After a heavy spring freshet, embankments are furrowed with deep gulleys, though the usual effect is the gradual wasting of the slopes. The only protection against these destructive agents is a good sod, and foremen should be supplied with grass seed of suitable variety to seed embankments whenever the conditions are favorable.

Until embankments are protected by grass they must be repaired from time to time. Narrow embankments give insufficient support to the track, and sags are the result. The fall of the year is the best time to repair embankments. All the material obtained from cleaning ditches, widening cuts, or from any other source, should be deposited upon the embankments where there is greatest need of repair. This material the section men can transport on a push car,

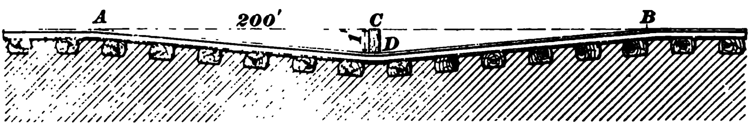


FIG. 512.

which should be fitted with sideboards so as to carry a full load. A section foreman can do much towards keeping his embankments in proper shape, especially if he be well provided with men. If there are bad sags on his section, he should not attempt to take them out until he knows how much material is required for raising the roadbed to the proper height. He can determine the necessary amount of filling by the following approximate method (see Fig. 512). Drive a stake at C against the rail at the middle point of the sag until its top is on line with the track surface at A and B. Measure the height $C\ D$ of the stake above the rail. Multiply one-half the distance $A\ B$ by the top width of the embankment and by the height $C\ D$ of the stake above the rail; divide the product by 27. The quotient is the number of cubic yards of material required.

EXAMPLE.—AB is 200 ft., CD is 1 ft., and the top of the embankment is 14 ft. in width; how many cubic yards of material are necessary to take out the sag?

SOLUTION.—Number of cubic yards $= \frac{200}{2} \times 14 \times 1 \div 27 = 52$, nearly, Ans.

A push car with sideboards will carry 1 cubic yard of material. If the men and material are at hand, commence by raising the sag near the middle, extending the raising on both sides until the ends are reached. Raise the track at the middle of the sag about $\frac{1}{10}$ higher than the total depth of the sag, to allow for shrinkage of the material.

1649. General Repairs.—Carefully examine all joints, tightening loose nuts and renewing bolts where they are broken or stripped of their thread. See that proper provision is made for expansion, and that all ties are full spiked. Rotten ties left over from the work of the previous spring should be replaced with new ones. If new steel is required, see to it that it is laid early in the fall and the track well settled before winter begins.

Thoroughly repair the right of way and snow fences. The winter season puts all fences to the test, and they should be in thorough repair if they are to do service the following summer.

1650. Building New Fence.—Though the spring is the most favorable season of the year for building fence, the more urgent track repairs fully occupy the time of every section man. Consequently, fence building is deferred until the late summer or fall. The one disadvantage to building fence when the season is well advanced is the hardness of the ground, which makes the digging of post holes much more laborious than in the early spring, when the ground is soft and yielding. There are, however, the following advantages in favor of building fence in the fall season. Posts and lumber are usually much better seasoned in the fall than in the spring; streams are low, and swampy places are either entirely dry or at least accessible. It is

important that posts should be peeled and well seasoned before setting; and as they are usually cut in the winter season, by delivering them at the section house in the winter or early spring, the section men can peel and pile them on stormy days; they will thus be thoroughly seasoned when needed the following fall.

The most effective fence is of barb wire with one board at the top, as shown in Fig. 513. Posts are spaced 8 feet between centers and set 2 feet 6 inches into the ground. At intervals of 500 feet on straight lines, and at every angle, braces *A B* should be built into the fence. The brace is mortised into the post at the top and gained into the post at the bottom. The wires are spaced as follows, beginning at the bottom wire, which is 9 inches above the ground: The first

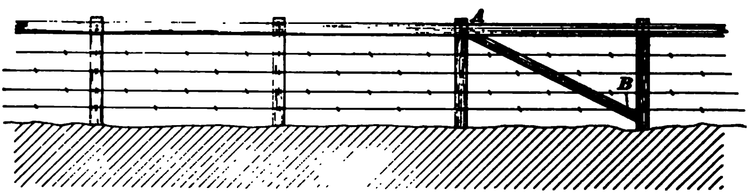


FIG. 513.

and second wires are 9 inches apart; the second and third, 10 inches; the third and fourth, 10 inches apart, and the fourth is spaced 10 inches from the top board or rail, which is 6 inches in width. This makes the total height of the fence 4 feet 6 inches, which is a lawful fence in most of the States, and the total length of the posts 7 feet. In laying out a fence, measure from the center line of the track, one-half the width of the right of way, and set a temporary post. Place these posts from 50 to 80 rods apart on tangents and from 50 to 100 feet apart on curves. Then stretch a light wire between these posts, with tags at intervals of 8 feet for spacing and lining the posts. A man then takes a lining bar and spade and plumbs down from each tag with the bar, making a mark with the point of the bar. He then removes the sod from around the hole made with the bar.

The hole marks the center of a post and guides the men who dig the post holes. The wire is removed while the holes are being dug, and replaced to give line for setting the posts. The diggers should be provided with a gauge giving the proper depth of hole. Those nailing on either boards or wire must be provided with a gauge giving top of fence and the spacing of each strand of wire. A handy gauge for spacing wires is shown in Fig. 514. It consists of a foot piece of pine 2 feet in length, 6 inches in width, and 1 inch in thickness. Another piece of pine 3 inches wide and 4 feet 6 inches in length, equal to the height of the fence, is nailed to the foot piece at its middle, as shown in the figure. The spacing of each wire from the ground is marked by a notch cut into the edge of the upright piece. The foot piece, besides giving the height from the average surface of the ground, helps to keep the gauge in an upright position.

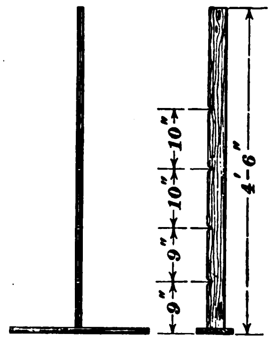


FIG. 514.

In building the fence described above, judgment should be used in distributing the force if first-rate progress is to be made. With a force of a dozen men, the following distribution is recommended: Two men to lay out the work, four digging holes, three setting posts, and three nailing on boards and stringing wires.

A wire stretcher is necessary to first-class work and progress, though good work at stretching wire can be done with a crowbar if sufficient care and strength is used.

At highway bridges and culverts, the fence usually returns to the ends of the abutments. The angles made in the fence by these returns must be thoroughly braced. Effective braces for such returns are shown in Figs. 515 and 516.

In Fig. 515 the angle of the return is 90°, and a brace in each panel abutting on the angle is sufficient, but in Fig. 516, where the angle contains 150°, an inside brace is added.

This brace abuts against a short post set in the ground to receive the thrust of the brace.

Braces must be placed at each opening, such as farm and

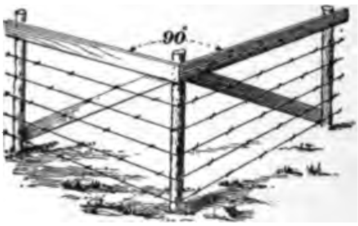


FIG. 515.

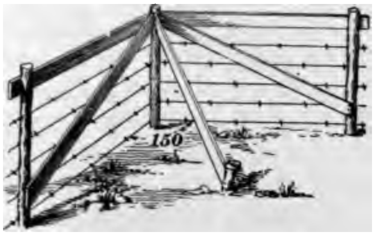


FIG. 516.

road crossings, and at all points where changes in direction require it.

At streams crossed by pile bridges, it is customary to make a return in the fence on both sides of the stream, and to string the wires across the stream, fastening them to the piles.

On tangents, and on the outside of curves, place boards and wire on the farmers' side of the posts, but on the inside of curves place them on the track side of the line of posts.

1651. Material for One Mile of Fence.—It will require 661 posts spaced 8 feet between centers to build one mile of fence. One fence board 16 ft. long, 6 in. wide, and $1\frac{1}{4}$ in. thick contains 10 sq. ft. of lumber, and 330, the number of boards required for 1 mile of fence, will contain $330 \times 10 = 3,300$ sq. ft.

Barb wire, of average weight, weighs 1 lb. per rod of single wire or 4 lb. per rod of finished fence. Hence, for 1 mile, or 320 rods, it will require $320 \times 4 = 1,280$ lb. Adding 10 lb. for splices, we have $1,280 + 10 = 1,290$ lb., the amount of barb wire required for 1 mile of fence. It will require $\frac{1}{8}$ lb. of staples for 1 rod of fence, and for 1 mile, or 320 rods, it will require $320 \times \frac{1}{8} = 40$ lb., and we have the following

TABLE OF MATERIAL FOR 1 MILE OF FENCE.

Posts.	Boards.	Barb Wire.	Staples.
661	3,300 sq. ft.	1,290 lb.	40 lb.

When barb-wire fences were first introduced, the posts and braces were the only wood material used, but they proved very injurious to live stock, which, failing to see the wire, continually came in hurtful contact with the barbs. This objection is removed by placing a single board for the top rail. This board clearly marks the fence line, and, together with the barb wire, makes the most effective fence known.

1652. A Day's Work at Fence Building.—From 12 to 14 rods per man is a fair day's work at fence building, though much depends upon the hardness of the ground, the quality of the work, and the skill and industry of the workmen. Fence building requires intelligent industry. A poorly built fence is little better than no fence.

1653. Distributing Emergency Material.—In the late fall, but before any snow falls, place at each mile post, and well up from the ground, a number of rails and joint splices to be used in case of emergency, and known as emergency material. Such supplies are available when most needed, and are constantly near at hand.

All track material lying about the yard should be collected and piled well off the ground. Piles of ties must be placed far enough apart to avoid catching fire from one another in case of fire. All loose spikes, splices, bolts, and nuts should be collected and placed under cover, and everything about the station made snug and safe for the winter.

WINTER TRACK WORK.

1654. General Repairs.—As winter approaches, the entire section should be gone over carefully, tightening up all loose splices, correcting defects in gauge, and closing up joints which the contraction of the rails has left too open.

The joints of switches are most liable to be open and the rails battered. Close up these joints and renew the rails if necessary. See that switch joints, rods, and frogs are in proper order, and that guard-rails are properly spaced and well spiked.

Keep all spikes driven home, clear the snow from yard tracks and switches, flange out the main track after every snow storm, and remove ice from the ditches.

1655. Shimming Track.—There is no work connected with track repairs requiring more care and judgment than shimming. All mud-ballasted tracks are bound to heave from the action of the frost, and heaving spoils the surface of the track. Inequalities as small as $\frac{1}{4}$ inch should be corrected by shims placed beneath the rail. Shims should be made of hard wood, slightly wedge-shaped, and driven crosswise under the rail. All shims over $\frac{1}{2}$ inch in thickness should have a hole bored in them to receive the spike. They are easiest made by boring a hole through the end of a straight-grained plank and cutting off a piece to the required length, after which the plank may be split into shims of the required thickness. If the rail has cut into the tie, the edges of the groove must be adzed smooth before placing the shims, in order that the rails may have a solid bearing. If the track continues to heave, thin shims must be replaced by thicker ones. Where a number of ties side by side require shimming, a plank should be placed lengthwise under the rail and spiked to the ties with boat spikes and track spikes driven through the plank to hold the rail. Where shims exceed 1 inch in thickness, spikes 7 or 8 inches in length should be used.

For 4-inch shims use 1-inch shims on top of 3-inch plank, and for 5-inch shims, use 5-inch timber. Where shims exceed 1 inch in thickness, old rail splices should be set with one end against the outside of the rail and the other end spiked to the tie to serve as rail braces. These braces should be spiked to every second, third, or fourth tie, according to the height of the shim.

All high-shimmed track should be closely watched, and

as the frost leaves the track and the track settles, thinner shims must be substituted for the thick ones. The last shim must not be removed until the frost has left the ground. When the shimmed rail is higher than the rest of the track by the thickness of the shim, you may know that the frost has left the track. All good shims, spikes, and braces should be stored in the tool house, to be in readiness when needed the following winter.

1656. Heaved Bridges and Culverts.—Pile bridges and pile culverts require careful watching during the winter season, and whenever they are found to be heaved out of surface or line, the bridge carpenters should be promptly notified. Pile foundations, when heaved by frost, unlike earth foundations, do not resume their original position after the frost has left the track. Neither does the frost affect them equally, as one or two piles in a bent may be heaved out of surface while the others are not stirred. This places the track in a dangerous condition. To remedy the evil, either the track must be shimmed to the surface of the heaved piles or they must be cut down to the original surface. Where piles are driven in deep water, the ice should be cut away from them whenever a thaw is imminent, as a sudden rise in the water may lift the body of ice, and the piles, being frozen fast in the ice, must rise also.

SNOW.

1657. Its Prevalence and Effects.—Nearly all roads in the Northern States are obliged to contend with snow, and, in the Northwest especially, the keeping of the track clear of snow constitutes one of the main items of cost of track maintenance. Snow must be contended with in many forms, the most common of which is drifted snow; but it is almost equally difficult to contend with it when it fills the flanges of the rails with ice, or in melting and freezing it fills the track ditches and flows across the track, covering the rails with ice and threatening derailment to the first passing train.

1658. Snow Reports.—Immediately after every snow storm, the section foreman should ascertain the condition of his track, noting which cuts are clear and which are blocked, and how much snow is in each cut, and the lengths of the drifts. These facts he should report immediately by telegraph to the roadmaster, in order that preparations may be made to clear the track. If the section is clear of snow, it should be so reported.

1659. Preparing Track for Snow Plow.—After a storm, as soon as the condition of the section has been reported to the roadmaster, the foreman should take all his force and put his section in shape for the snow plow. In all cuts where the drifts are over two feet in depth, the track should be cleared of snow and flanged out to where the snow has a depth of at least 18 inches, leaving a clean face to the drift. Both ends of the cut should have the same treatment. Snow is most apt to cause derailment when it is of slight depth and hard, and so ground into the flanges that the engines mount the rail. By clearing the track of snow at the commencement and ends of drifts, this danger is avoided.

1660. Clearing Switches and Flanging Track.—As soon as the track is ready for the snow plow, the men should clear the switches of snow from heel of switch to frog, special care being taken to clear the switch rails, rods, and switch stand. The platform, track, and approaches to the station should also be promptly cleared.

The section foreman should next give his attention to flanging out the main track, beginning near the summits of the hard grades, and at all points where the work upon the engines is most severe.

1661. Clearing Ditches and Culverts.—If possible, keep the ditches and culverts clear of snow. If, in the fall, a tall stake is driven at both ends of a culvert opening, there will be no trouble in locating it when the culvert is completely covered with drifted snow. By keeping the ditches open, all snow water can run off instead of accumulating and flooding the track, where it is bound to freeze, making

the track not only hard to operate, but a continual menace to the safety of trains. The ditch for snow water should be fully 6 feet from the rails to insure the safety of the track.

1662. Snow Fences.—All railroads exposed to severe and repeated snow storms should have some protection against drifting snow. This protection is best provided in the form of fences. Their efficiency will depend upon their strength, height, position, and distance from the track. The fence should be placed at such a distance from the track that, when drifted full, the snow will not reach within 30 feet of the track. To effect this, the distance of the fence from the track should be 12 feet for each foot in height of fence. When the fence is placed too near the track, the snow will be carried to the track before the fence is drifted full; if, on the other hand, the fence is placed too far from the track, the wind, after clearing the fence, will fall and gather up all the snow between the foot of the drift and the track, and carry it into the cut. Usually but one side of the track requires protection from snow, viz., that side from which snow storms most prevail. Most railroads in the snow belt of the United States run in two general directions, viz., east and west, and as most of the severe storms prevail from the north, northwest, and northeast, the north side of most tracks is the only one requiring protection from snow. At some exceptional points on the line, the topography of the country may cause complex currents of air which may produce results at variance with general rules. At all points, fences should be built to meet the existing conditions. In general, snow fences are built parallel to the track. For fences of ordinary height, the following rule can be safely followed: Place the fence 75 feet from the nearest track rail, extending it parallel to the track the entire length of the cut. Change the direction of the fence at both ends of the cut, gradually approaching the track until the ends of the fence are 100 feet from the ends of the cut and 50 or 60 feet from the track.

If the cut ends abruptly at the beginning of a high embankment, the turn in the fence must be made before the end of

the cut is reached, in order to protect the cut from head and quartering winds. Cuts which are lined on the storm side by brush or heavy timber do not require fencing, as the only snow which reaches the track is that which falls directly upon it. The brushwood and timber prevent the blowing of the snow. Cuts made in a side hill where the ground slopes off abruptly into a valley do not require fencing. But where there is a long level or gently rolling stretch of ground on the storm side of the track, the cut is liable to drift full unless properly fenced. When a fence becomes drifted full, its height may be readily increased by adding a wall of blocks of snow taken from the inside face of the drift. So long as the weather remains cold a snow wall will serve the full purpose of a fence.

A first-class snow fence, kept in perfect repair, will not last above 10 years, and it becomes a question whether to build a snow fence or grade down the cut so that it will not hold snow. The items of cost to be considered are the first cost of the fence, the annual repairs, the interest on each charge for the time it is to serve in the fence, and if these combined items equal or exceed the cost of grading down the slopes so as to keep the cut clear of snow, the grading should be done.

1663. Bucking Snow.—The clearing of the track of snow belongs to the Roadmaster's Department, but it is essentially *track work* and at times of vital importance to a railroad.

A man should be thoroughly familiar with the best methods of bucking snow before taking charge of an outfit to open up a road for traffic after a blockade.

Before starting out on the road, he should be as thoroughly informed as possible as to the condition of the road, the location, length, and depth of drifts. He should have strong, live engines and willing engineers. The snow plow should be of the best make and able to throw snow out of a 10-foot cut. There should be two engines in the outfit. The second engine follows closely, with a car, conductor, train

crew, and shoveling gang. When heavy drifts are encountered too deep for one engine to successfully buck, the second engine is coupled to the first, and besides doubling the momentum, serves to pull out the head engine and plow in case they are stalled. The pilot should be removed from the second engine, and the coupling made short and very strong. No car or caboose should ever be placed between the engines, as they are likely to cause a wreck. When the drifts are more than 10 feet deep, the top of the drift must be shoveled out down to that depth, and a space made wide enough that effective work may be done by the plow.

When the snow is reported hard, each drift must first be carefully examined and its length and height noted. If the drift has not been faced by section men (that is, shoveled out from the end of the drift to where its depth is from 15 to 18 inches), the gang of shovelers must do the work before a run is made with the plow.

Unless the drifts are properly faced, the plow is liable to mount the rails, especially on curved track, and often the engine is derailed along with the plow. All cars attached to the helper engine should be left behind while bucking snow. If both engines are not necessary to buck a drift, it is better to do the work with one. The helper engine should only be used where necessary. If the snow is not too hard, a good, heavy engine will clear a drift from 3 to 5 feet deep and from 500 to 800 feet in length at one run. There is comparatively no danger in bucking soft, deep snow with an engine at top speed.

The engines with a snow-plow outfit should take fuel and water to their utmost capacity at every point reached where a supply can be obtained. Unforeseen delays and mishaps may be encountered, and there must be no risk of a short supply of fuel or water. When the road is badly blockaded, the helper engine should carry an extra carload of coal. The water supply can be readily replenished by shoveling snow into the tank.

Each engine in the outfit should carry a piece of steam hose, which can be attached to the siphon cock, and reach

from it to the water hole in the tender. When the water supply needs replenishing, by shoveling snow into the tender and turning on the steam, a tank full of water can be quickly made. The steam hose can also be used to thaw the snow and ice from the machinery and track rails.

In plowing snow the speed of the engine should always be regulated by the length and depth of the drifts. When the drift is deep and long, the engine should back up far enough to attain full speed before striking the drift. An experienced engineer will so regulate the speed of his engine as to leave but little work for the shovelers.

The engineer of the plow engine should always sound the whistle when approaching a cut, in order that section men, if working there, may be warned in time to get out of the cut. Failure to sound the whistle has been a frequent cause of accident. When it is necessary to buck a drift a second time, the engineer must sound the whistle and be sure that all hands are out of the cut before entering it. It is almost impossible for men to climb up out of a snow cut when first opened up.

When the snow drift is of such depth and length that two runs are likely to not clear it, it is the better policy to shovel out from both ends until it is certain that two runs will leave a clear track.

When the snow is both deep and very hard, the crust should be broken up and shoveled out before any attempt is made with the plow. Bucking deep, hard snow with the crust unbroken is very severe work for a locomotive, and is often attended with danger to trainmen. It is far better to insure safety even at the price of delay. It is not advisable to start out to clear a track of snow during a heavy storm, but everything should be in readiness to start the moment the storm abates.

The invention of the rotary snow plow has practically solved the snow problem, especially for clearing the track of hard snow. Many roads which suffer little from snow do not yet possess rotary plows, and the old custom of bucking snow is still practised when occasion requires it.

CURVED TRACK.

1664. Difference in Length of Inner and Outer Rails of a Curve.—It is evident that the radius of the outer rail of a curve is greater than that of the inner rail, and, consequently, its length is greater. This difference may be taken at $1\frac{1}{32}$ inches per degree of curve per 100 feet, for standard gauge track. The difference in length between the inner and the outer rails of a curve may be found by any of the three following rules:

Rule 1.—*Multiply the degree of the curve by the length in stations of 100 feet, and this product by $1\frac{1}{32}$ inches. The result will be the difference in length between the inner and outer rails in inches.*

EXAMPLE.—The degree of a curve is 4°; its length 520 feet; what is the difference in length between the inner and outer rails of the curve?

SOLUTION.—520 feet = 5.2 stations of 100 feet each. $4 \times 5.2 = 20.8$. $1\frac{1}{32}$ in. = 1.03125 in. $20.8 \times 1.03125 = 21.45$ in. = 1.7875 ft. Ans.

Rule 2.—*Multiply the distance between the center lines of the rails by the length of the curve in feet and divide the product by the radius of the track curve.*

EXAMPLE.—A 4° curve is 520 feet in length; the distance between the center lines of the rails is 4 ft. $10\frac{1}{2}$ in.; what is the difference in length between the inner and outer rails of the curve?

SOLUTION.—The radius of a 4° curve is 1432.69 ft. (See table of Radii and Deflections.) $10\frac{1}{2}$ in. reduced to the decimal of a foot is .875 ft. $\frac{4.875 \times 520}{1,432.69} = 1.77$ ft. Ans.

Rule 3.—*Multiply the excess for a whole circumference by the total number of degrees in the curve, and divide the product by 360. The excess of a whole circumference, no matter what the degree of curve, is equal to twice the distance between rail centers multiplied by 3.1416.*

EXAMPLE.—A 4° curve is 520 feet in length; the distance from center to center of the rails is 4 ft. $10\frac{1}{2}$ in.; what is the difference in length between the inner and outer rails of the curve?

SOLUTION.—The distance between rail centers is 4.875 ft. $4.875 \times 2 \times 3.1416 = 30.6306$ ft. A 4° curve for 520 ft. contains 20.8°. $30.6306 \times 20.8 \div 360 = 1.77$ ft. Ans.

For light curves laid to exact gauge, the first rule is the simpler one, but for short curves where the gauge is widened use either the second or the third method.

These rules should be applied in determining the number of short rails for curves, when loading material at the supply yard for forwarding to the track layers. As previously stated, a safe rule is one 29½-foot rail per 100 feet for each 6 degrees of curvature. In laying track with either even or broken joints, the required number of short rails must be laid in proper order if a first-class job is to be expected.

1665. Curving Rails.—When laying track on curves, in order to have a smooth line, the rails themselves must conform to the curve of the center line. To accomplish this the rails must be curved. The curving should be done with a rail bender (see Fig. 495) or with a lever, as shown in Fig. 497. The rail bender is preferable.

To guide those in charge of this work, a table of middle and quarter ordinates for a 30-foot rail for all degrees of curve should be prepared.

The accompanying table of middle ordinates for curving rails is calculated by using the formula

$$m = \frac{c^2}{8R}, \qquad \textbf{(112.)}$$

in which m is the middle ordinate; c, the chord, assumed to be of the same length as the rail, and R, the radius of the curve.

EXAMPLE.—What is the middle ordinate m of a 30-foot rail for an 8° curve?

SOLUTION.—The radius of an 8° curve is 716.78 ft.

Applying the formula, we have

$$m = \frac{30^2}{8 \times 716.78} = \frac{900}{5,734.24} = 0.157 \text{ ft.} = 1\tfrac{7}{8} \text{ in. Ans.}$$

The results obtained from this formula are not theoretically correct, yet the error is so small that it may be ignored in practical work. With a table of radii such as is given in the table of Radii and Chord and Tangent Deflections, a table of ordinates may be readily calculated by substituting the known values in formula **112.**

TABLE 32.

MIDDLE ORDINATES FOR CURVING RAILS.

Degree of Curve.	Lengths of Rails.					
	30 Ft.	28 Ft.	26 Ft.	24 Ft.	22 Ft.	20 Ft.
	In.	In.	In.	In.	In.	In.
1	$0\frac{1}{4}$	$0\frac{3}{16}$	$0\frac{3}{16}$	$0\frac{3}{16}$	$0\frac{1}{8}$	$0\frac{1}{8}$
2	$0\frac{1}{2}$	$0\frac{7}{16}$	$0\frac{3}{8}$	$0\frac{5}{16}$	$0\frac{1}{4}$	$0\frac{3}{16}$
3	$0\frac{11}{16}$	$0\frac{5}{8}$	$0\frac{9}{16}$	$0\frac{7}{16}$	$0\frac{3}{8}$	$0\frac{5}{16}$
4	$0\frac{15}{16}$	$0\frac{13}{16}$	$0\frac{11}{16}$	$0\frac{5}{8}$	$0\frac{1}{2}$	$0\frac{7}{16}$
5	$1\frac{3}{16}$	$1\frac{1}{16}$	$0\frac{7}{8}$	$0\frac{3}{4}$	$0\frac{5}{8}$	$0\frac{9}{16}$
6	$1\frac{7}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$0\frac{7}{8}$	$0\frac{3}{4}$	$0\frac{5}{8}$
7	$1\frac{5}{8}$	$1\frac{7}{16}$	$1\frac{1}{4}$	$1\frac{1}{16}$	$0\frac{7}{8}$	$0\frac{3}{4}$
8	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{7}{16}$	$1\frac{3}{16}$	1	$0\frac{7}{8}$
9	$2\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{5}{8}$	$1\frac{3}{8}$	$1\frac{1}{8}$	$0\frac{15}{16}$
10	$2\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{3}{4}$	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{1}{16}$
11	$2\frac{5}{8}$	$2\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{11}{16}$	$1\frac{3}{8}$	$1\frac{1}{8}$
12	$2\frac{13}{16}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{13}{16}$	$1\frac{9}{16}$	$1\frac{1}{4}$
13	$3\frac{1}{16}$	$2\frac{11}{16}$	$2\frac{5}{16}$	$1\frac{15}{16}$	$1\frac{5}{8}$	$1\frac{3}{8}$
14	$3\frac{5}{16}$	$2\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{1}{8}$	$1\frac{3}{4}$	$1\frac{1}{2}$
15	$3\frac{9}{16}$	$3\frac{1}{16}$	$2\frac{11}{16}$	$2\frac{1}{4}$	$1\frac{15}{16}$	$1\frac{9}{16}$
16	$3\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{13}{16}$	$2\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{11}{16}$
17	4	$3\frac{1}{2}$	3	$2\frac{9}{16}$	$2\frac{3}{16}$	$1\frac{3}{4}$
18	$4\frac{3}{16}$	$3\frac{11}{16}$	$3\frac{3}{16}$	$2\frac{11}{16}$	$2\frac{5}{16}$	$1\frac{7}{8}$
19	$4\frac{7}{16}$	$3\frac{7}{8}$	$3\frac{3}{8}$	$2\frac{7}{8}$	$2\frac{7}{16}$	2
20	$4\frac{11}{16}$	$4\frac{1}{8}$	$3\frac{9}{16}$	3	$2\frac{9}{16}$	$2\frac{1}{8}$

In curving rails, the ordinate is measured by stretching a cord from end to end of the rail against the gauge side, as shown in Fig. 517. Suppose the rail *A B* is 30 feet in length, and the curve 8°. Then, by the previous problem, the middle ordinate at *a* should be $1\frac{7}{8}$ inches. To insure a uniform curve to the rails, the ordinates at the quarters *b* and *b'* should be tested. In all cases the quarter ordinates should

be three-quarters of the middle ordinate. In Fig. 517, if the rail has been properly curved, the quarter ordinates at b and b' will be $\frac{3}{4} \times 1\frac{7}{8}$ in. $= 1\frac{13}{32}$, say $1\frac{3}{8}$ in.

With practice, a man having a good eye and good judgment will soon find his eye measurements closely checking his table measurements. When a quantity of rails are to be curved for curves of different degrees, it is a good plan to

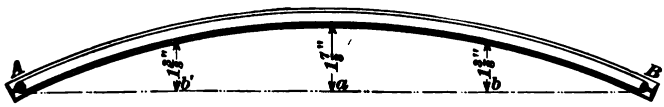


FIG. 517.

mark the degree of the curve of each rail in white paint on the web of the rail on the concave side. There should be ample force to handle the rails with dispatch, else much time will be wasted. The use of sledges in curving rails should under no circumstances be allowed. There is great danger of fracture, and often a flaw is caused which at the time is not perceptible, but which may, under the stresses caused by frost and heavy trains at high speed, result in a broken rail, with serious consequences.

In track work it is often necessary to ascertain the degree of a curve, though no transit is available for measuring it. The following table contains the middle ordinates of a one degree curve for chords of various lengths:

TABLE 33.

Length of Chord in Feet.	Middle Ordinate of a 1° Curve.
20 ft.	$\frac{1}{8}$ in.
30 ft.	$\frac{1}{4}$ in.
44 ft.	$\frac{1}{2}$ in.
50 ft.	$\frac{5}{8}$ in.
62 ft.	1 in.
100 ft.	$2\frac{5}{8}$ in.
120 ft.	$3\frac{3}{4}$ in.

The lengths of the chords are varied so that a longer or shorter chord may be used, according as the curve is regular or not.

The table is applied as follows: Suppose the middle ordinate of a 44-foot chord is 3 inches. We find in the table that the middle ordinate of a 44-foot chord of a one-degree curve is $\frac{1}{2}$ inch. Hence, the degree of the given curve is equal to the quotient of $3 \div \frac{1}{2} = 6°$ curve.

Additional examples are given as follows:

1. The middle ordinate of a 100-foot chord is $14\frac{3}{4}$ inches; what is the degree of the curve? Ans. 5.6°, nearly.

The degree of the curve is probably 5° 30′.

2. The middle ordinate of a 50-foot chord is $5\frac{1}{4}$ inches; what is the degree of the curve? Ans. 8.4°.

The degree of the curve is probably 8° 30′.

3. Calculate by rule 1 the difference in lengths between the inner and the outer rails of a 7° curve 475 feet in length. Ans. 34.29 in. = 2.857 ft.

4. Solve Example 3 by rule 2. Ans. 2.827 ft.

1666. Springing Rails into Curve.—Rails should never be sprung and spiked to a curve; the elastic force of the steel is constantly acting, and is sure to force the track out of line. Each passing train, through its centrifugal force, aids the rails to regain their original form. The result is that in a short time the curve, especially if a sharp one, will show an angle at each joint. The effect at these angles is to cause a sudden lurch of the car at each joint, causing not only discomfort to passengers, but serious and constant wear and strain upon the rolling stock.

1667. Widening Gauge of Curves.—In passing over curved track, the car wheels bind hard against the outside rail at the curve. The reason for this is that the difference between the gauge of the track and the gauge of the wheels is taken up by the wheel base, which forms a chord to the curve of the track, instead of being parallel to the rails, as is the case on a straight line. To lessen this friction,

the gauge is usually widened on curves to the amount of $\frac{1}{16}$ inch per degree, but never to exceed 1 inch on any curve. The increase in gauge is usually made in quarter-inches, that being the amount allowed for 4 degrees. The necessity for widening the gauge on sharp curves is still more apparent when we consider that provision must be made to accommodate cars of both standard gauge (4 feet $8\frac{1}{2}$ inches) and for those of 4 feet 9 inches gauge, common to Southern roads.

When the gauge is not widened, a wide-gauged car is liable to mount the rail, especially if the flanges of the wheels are badly worn and sharp. The effect of all curvature is to increase the train resistance, and on sharp curves, this resistance, due to friction, becomes so great as to largely reduce the train load. All train loads are limited by the maximum resistance which they must overcome. This maximum resistance may be concentrated upon a single curve, and it is at once apparent that a railroad company might well incur heavy expense in reducing this curvature, if by so doing they could add one extra car to each train load. Another charge against curvature is the loss of time to passenger trains which can not run over sharp curves, except at reduced speed. All curves exceeding eight degrees, besides their resistance to trains, cause a direct loss of time to all fast passenger trains.

1668. Guard Rails on Short Curves.—On straight track, laid to exact gauge, the guard rail is spaced $1\frac{3}{4}$ inches from the gauge rail; but when the gauge is widened, as on sharp curves, the amount of the increase in gauge must be added to the space between the gauge and the guard rail.

1669. Lining Curves.—A common habit of trackmen when lining curves is to throw the curve outwards to line. The effect of this, in time, is to reduce the degree of curvature at the ends of the curve and sharpen it at the center, besides crowding the roadway on the outside of the curve.

A safe rule is to always throw the track *inwards*, i. e., towards the center of the curve. It is at once apparent that the effect of the centrifugal force of the train in passing over a curve is to throw the track outwards, and in lining curves, the track should be thrown inwards, if for no other purpose than to overcome this effect of the trains. The effect of throwing the track outwards when lining a curve is shown in Fig. 518, in which *A B C* represents the true line of the curve and *A E C* the position of the tracks due to improper lining.

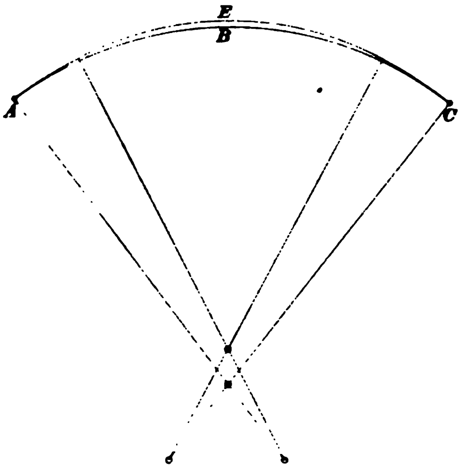


Fig. 518.

When track is first laid, there should be a track center stake driven at every 50 feet and carefully centered with a tack. Before and after ballasting, the track should be carefully lined to the center stakes, and if the rails have been properly curved the track will hold its line, with occasional retouching, for years.

In the case of a badly lined curve, select a piece of track 60 feet in length, which appears to be in good line. There are few curves, however badly out of line, but will show at least 60 feet of good line. At each end of the 60 feet of good track set an accurate center stake, and one in the center of the track midway between them. In Fig. 519, *A* and *B* represent the center stakes 60 feet apart, and *C* the stake midway between them. Stretch a cord from *A* to *B*, and measure the distance from *L*, its middle point, to *C*. The distance *C L* is the middle ordinate of a 60-foot chord. Next, mark the middle point *L* of the chord, and move the end *A* of the chord to *C*. Measure from *B* the

distance $B M = C L$, and carry the measuring cord forwards, stretching it taut, and in the line $C M$, as determined by the offset $B M$. The forward end D of the cord will mark the spot for another track center. Then, move ahead as before, measuring another offset and stretching the cord to locate another center stake at E. In this way a perfect curve may be run in without the use of an instrument. It is better policy to set the track centers in line with the faces of the stakes for line rather than the tack centers, as the cord is sure to line properly to the faces of the stakes, but in order

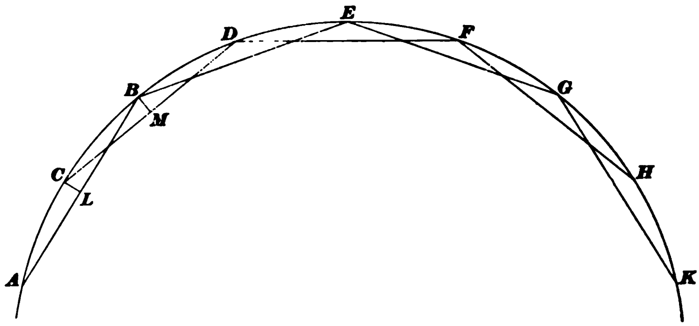


FIG. 519.

to line their centers they must be practically of the same height, which is sometimes difficult to obtain, especially if the ballast contains stone.

Having set all the track centers, select a track gauge which is square and true, and mark a point midway between the gauge lines. Then, place the gauge on the track close to the track center, and direct the men to move the track until the middle point of the track gauge coincides with the track center. Line up the track at each track center until the entire curve has been moved to line; then, repeat the operation, giving the final touches, as a second lining should be sufficient.

1670. Elevation of Curves.—To counteract the centrifugal force which is developed when a car passes around a curve, the outer rail is elevated. The amount of elevation will depend upon the radius of the curve and the speed at

which trains are to be run. There is, however, a limit in track elevation, as there is a limit in widening gauge, beyond which it is not safe to pass.

When we consider that the centrifugal force of a car increases *as the degree of curvature*, and *as the square of the speed*, we readily see how a slight decrease in speed will equalize a great increase in curvature.

To illustrate: A car passing around an 8-degree curve will have double the centrifugal force of a car passing around a 4 degree curve at the same speed. But to neutralize the effect of sharpening the curve from 4 to 8 degrees, it is not necessary to halve the speed, but only to reduce it in an inverse proportion to the square root of the degrees of curvature. Thus, if a speed of 60 miles per hour is admissible on a 4-degree curve, the speed on an 8-degree curve is obtained by the proportion $60 : x = \sqrt{8} : \sqrt{4}$, or $x = 42.43$ miles per hour. If we again double the degree of the curve to 16 degrees, we only reduce the admissible speed of equal safety to 30 miles per hour. Hence, it will be seen that the centrifugal force developed by an increase in speed is not proportional to the centrifugal force developed by an increase in curvature. In consequence of this varying relation between curvature and speed, no fixed rule can be followed for elevating the outer rail of curves.

It is a safe rule to elevate all curves to suit the highest speed of trains passing over that part of the track. Ordinarily freight trains require the same track elevation as passenger trains. All railroad men know that freight trains repeatedly run at passenger train speed. The aim of every freight train conductor is to "make time," and he makes it whenever the grades and train loads permit.

On rolling grades it is often necessary to run down a grade at top speed in order to acquire sufficient momentum to carry the train to the summit of the following grade. Every day fast running is necessary in order to make up for time lost through unavoidable delays; hence, if a curved track is elevated to meet the requirements of passenger trains, freight trains will be equally well served. All curves, when possible,

should have an elevated approach on the straight main track, of such length that trains may pass on and off the curve without any sudden or disagreeable lurch. The length of the approach should be in proportion to the elevation of the curve and not to its degree.

A good rule for curve approaches is the following: For each half-inch or fraction thereof of curve elevation, add 30 feet or 1 rail length to the approach; that is, if a curve has an elevation of 2 inches, the approach will have as many rail lengths as $\frac{1}{2}$ is contained in 2, which is 4 times. The approach will, therefore, have a length of 4 rails of 30 feet each, or 120 feet.

The following formula by Searles, viz.,

$$c = 1.587\ V, \qquad \textbf{(113.)}$$

gives the length of the chord c, whose *middle ordinate* is equal to the *proper elevation* of the outer rail of the curve for any velocity V in miles per hour.

EXAMPLE.—The curve is 8°, and the velocity 40 miles per hour; what is the proper elevation for the outer rail of the curve?

SOLUTION.—Substituting the given values in formula **113**,

$$c = 1.587\ V,$$

we have $c = 1.587 \times 40 = 63.48$ feet, the length of the required chord.

To find the middle ordinate of this chord, we apply formula **112**.

We have just found $c = 63.48$ feet, and $R =$ the radius of an 8° curve $= 716.78$ feet.

Substituting these values of c and R in the above formula, we have

$$m = \frac{63.48^2}{8 \times 716.78} = \frac{4{,}029.7}{5{,}734.2} = .71 \text{ ft., nearly} = 8\tfrac{1}{2} \text{ in.} \quad \text{Ans.}$$

This result is too great. The best authorities on this subject place the maximum elevation at $\frac{1}{7}$ the gauge, or about 8 inches for standard gauge of 4 feet $8\frac{1}{2}$ inches. The gauge on a 10° curve elevated for a speed of 40 miles an hour should be widened to 4 feet $9\frac{1}{4}$ inches.

The following table for elevation of curves is a compromise between the extremes recommended by different engineers. It is a striking fact that experienced trackmen never elevate track above 6 inches, and many of them place the limit at 5 inches:

TABLE 34.

Degree of Curve.	Length of Approach.	Elevation.	Width of Gauge.	Speed of Trains.
1	60 ft.	1 in.	4 ft. 8½ in.	60 mi. per hr.
2	120 ft.	2 in.	4 ft. 8½ in.	60 mi. per hr.
3	150 ft.	2½ in.	4 ft. 8¾ in.	60 mi. per hr.
4	180 ft.	2¾ in.	4 ft. 8¾ in.	55 mi. per hr.
5	180 ft.	3 in.	4 ft. 8¾ in.	50 mi. per hr.
6	210 ft.	3¼ in.	4 ft. 8¾ in.	45 mi. per hr.
7	210 ft.	3½ in.	4 ft. 9 in.	40 mi. per hr.
8	240 ft.	3¾ in.	4 ft. 9 in.	35 mi. per hr.
9	240 ft.	4 in.	4 ft. 9 in.	30 mi. per hr.
10	270 ft.	4¼ in.	4 ft. 9 in.	25 mi. per hr.
11	270 ft.	4½ in.	4 ft. 9¼ in.	20 mi. per hr.
12	270 ft.	4¾ in.	4 ft. 9¼ in.	15 mi. per hr.
13	240 ft.	4½ in.	4 ft. 9¼ in.	10 mi. per hr.
14	240 ft.	4¼ in.	4 ft. 9¼ in.	10 mi. per hr.
15	240 ft.	4 in.	4 ft. 9½ in.	10 mi. per hr.
16	240 ft.	4 in.	4 ft. 9½ in.	10 mi. per hr.

Many persons overrate the objections to sharp curves, especially where the grades are low. Their great objection is not in their being an obstacle to high speed, but in their great resistance to traction. Freight trains, which are usually heavily loaded, are much more impeded by sharp curves than passenger trains, which are generally lighter and made up of cars which more readily adjust themselves to irregularities in line and surface.

No curve exceeding 10 degrees should be placed in the main line of any railroad. The additional cost of operating and maintaining a sharper curve would pay for the additional outlay necessary to bring the degree within the 10-degree standard. Many roads place the maximum curve at 6 degrees, and though beyond the reach of many roads, it is a safe standard.

Besides the loss of time necessitated by running slowly on short curves, there is a much greater loss due to the wear and tear on rolling stock and upon the rails themselves. The friction of the wheel flanges against the rails rapidly wears them out, and the continual lurching and rolling of the cars detract greatly from the comfort of passengers.

Most of the trunk lines in the United States have been greatly improved since their first construction, especially in their alinement, some of them being practically rebuilt. The Pennsylvania R. R. between Philadelphia and Harrisburg is a striking instance of the great improvement, both in alinement and grade, of a line originally cheaply and poorly built. Many of the original curves have been removed, and all of them lightened. In many places the original line has been entirely abandoned, and a new and better one adopted. This road is, however, an exceptional case, as few lines in the world could afford to make slight changes involving so great cost.

1671. The Elevation of Turnout Curves.—The speed of all trains in passing over turnout curves and cross-overs is greatly reduced, so that an elevation of $\frac{1}{4}$ inch per degree is amply sufficient for all curves under 16 degrees. On curves exceeding 16 degrees, the elevation may be held at 4 inches until 20 degrees is reached, and on curves exceeding 20 degrees, $\frac{3}{16}$ of an inch of elevation per degree may be allowed until the total elevation amounts to 5 inches, which is sufficient for the shortest curves.

1672. Curve Approaches Between Reverse Curves.—If possible, there should be a level piece of track, at least 60 feet in length, between reverse curves, besides the elevated approaches to the curves. When the whole of the intermediate tangent is required in making the elevated approaches to the curves, commence at the middle of the intermediate tangent, if both curves are of the same degree. If, however, they are of different degrees, make the approach to each curve in proportion to its degree. In elevating the approaches to the curves, give to the first rail

length an elevation of ½ inch, after which give ½ inch additional elevation per rail length, or, if necessary, 1 inch additional elevation, so as to make the total elevation of the approach equal to the elevation of the outer rail of the curve.

When a curve is compounded, commence to increase or decrease the elevation far enough back from the point of compound curvature to give to the second branch of the compound curve the elevation which it requires. This increase or decrease in elevation is made at the rate of ½ inch per rail length, precisely as in elevating the approach to a regular curve. When the changes in a compound curve are frequent and abrupt, it is best to elevate the outer rail for the highest degree of the curve and carry this elevation uniformly throughout the curve.

1673. Putting the Elevation in Curves.—If the track is in good surface, first catch up all the low joints on the inner rail of the curve. The elevation of the outer rail is determined by means of the **track level** shown in Fig. 520. For leveling track, the edge *a b* of the track level is

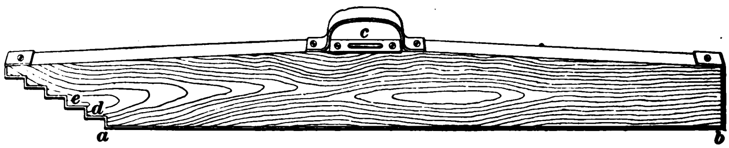


FIG. 520.

placed upon the rails, and when perfectly level the bubble *c* of the spirit level will rest in the middle of the tube. The steps *d*, *e*, etc., of the track level are made 1 inch in height, so that when the step *d* is placed on the outer rail of a curve and the rail raised until the bubble of the spirit level rests in the middle of the tube, the outer rail has an elevation of 1 inch. Similarly, the step *e*, when brought to a level, would indicate a track elevation of 2 inches, etc.

Having determined the amount of elevation required for the curve, the outer rail is raised with the track jack and the ballast thoroughly tamped under the ties. The elevation

should be about ½ inch in excess of that required, in order that provision may be made for settlement.

In dressing the track after the elevation has been made, make the crown of the ballast at not more than one-third of the width of the gauge from the outer rail, in order to secure drainage. The raising of the outer rail reduces the outer slope and increases the inner slope of the ballast. If the curve is sharp, the ballast on the outer half of the track is practically level and holds water, instead of shedding it. By crowning the ballast as directed, thorough drainage is insured.

1674. The Effects of Curved Track upon Locomotive and Car Wheels.—The effect of all curved track, however easy the curve, is to wear the flanges and treads of car wheels. This effect is due to the centrifugal force which forces the flanges of the wheels against the head of the outside rail of the curve.

The elevation of the outer rail, the widening of the gauge, and the coning of the car wheels, all combine to reduce this friction and consequent wear.

Where the elevation is insufficient, the friction increases, and if the gauge is the same as on straight track, there is great danger of the wheels mounting the rails, especially if the flanges are badly worn. The conclusion from many years of experiment and close observation is that the wear of rails on curved track is largely due to the driving wheels of the engine. When the tires become worn, the wear of the rails rapidly increases, and hence the importance of careful and repeated inspection of the driving wheels. As soon as they show considerable wear, the tires should be turned off to true lines. Besides preventing unnecessary wear of rails, this greatly increases the tractive power of the engine. When the treads of car wheels become badly worn, especially at the flanges, there is bound to be more or less slipping of the wheels. For the outer rail, being the circumference of a greater circle, should require a wheel of greater diameter than the inner wheel, if both are to make

the same number of revolutions. This increased diameter is given by the *coning of the wheels*, shown in Fig. 521, in which the rail *a* is on the outside of the curve. An inspection of the figure will show that the cone-shaped tread of the wheel *b* gives a greater diameter to the wheel at *c d* than at *e f*. In passing around the curve, the flange of the wheel *b* is forced against the rail *a*, while the flange of the wheel *h* recedes from the rail *g*. This increases the diameter of the wheel *b*, while decreasing that of the wheel *h*, and so the ex-

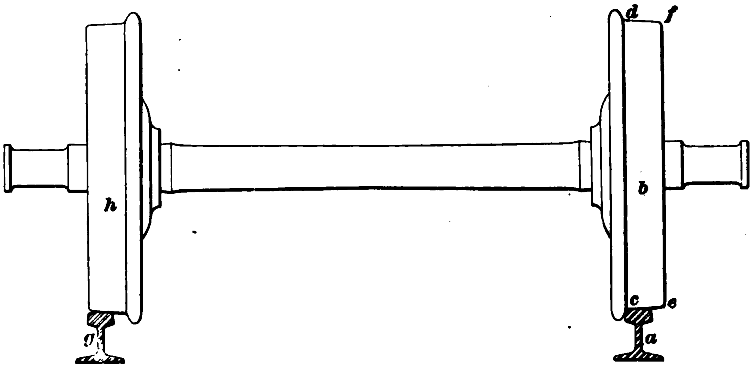


FIG. 521.

cess in length of the outer rail of the curve is at least partially covered.

Careful experiment proves that under the most favoring conditions some *slipping* of the wheels is bound to occur. The friction between wheels and rails rapidly increases as the rails become worn, and, as soon as the head of the outer rail of a curve becomes badly worn, the outer rail should be taken up and placed on the inside of the curve, and the inner rail put in its place. This furnishes almost new wearing surfaces to the wheel, and the life of the rails is greatly prolonged.

1675. Care of Curved Track.—As curved track offers greater resistance and greater danger to passing trains than straight track, special effort and pains should be taken to maintain it in perfect order. All trackmen know that a low spot on a curve will cause every car in a train to

lurch heavily towards the low side. By careful watching, and by prompt and thorough repairs, curved track may be kept in perfect order. It is highly important that the elevation of the outer rail be kept uniform, and no foreman, however experienced, should place dependence upon his eye in estimating curve elevation.

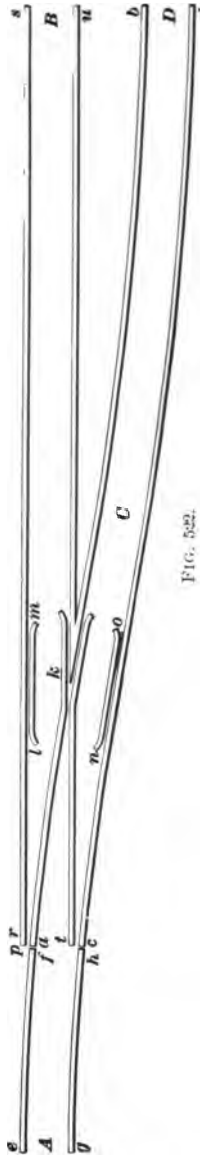


Fig. 522.

Both the civil engineer and the track foreman will do well to cultivate each other, the engineer imparting theoretical knowledge in exchange for practical knowledge. The result will certainly promote mutual respect and enhance the efficiency of both.

FROGS AND SWITCHES.

FROGS.

1676. Turnouts.—A turnout is a device for enabling an engine and train to pass from one track to another. It consists of two lines of rails $a\ b$ and $c\ d$ (see Fig. 522), so laid as to form a reversed curve uniting the two tracks $A\ B$ and $C\ D$. The several parts of a turnout are as follows: The **switch rails** $e\ f$ and $g\ h$, the **frog** k, and the two **guard-rails** $l\ m$ and $n\ o$. The stationary ends e and g of the switch rails are called the **heels,** and the movable ends f and h are called the **toes.** The distance $f\ p$, through which the toes f and h move, is called the **throw.** The throw must equal the width of the head of the rail, with sufficient additional width to allow the flanges of the wheels to pass freely between the main rails $r\ s$ and $t\ u$ and

the turnout rails *a b* and *c d*. The throw on tracks of standard gauge is 5 inches; that is, the toes *f* and *h* are moved 5 inches from their original position in the main track in forming the turnout curve on which the train is to pass from the main track *A B* to the siding *C D*.

The movement of the switch rails is effected by means of a lever.

1677. The Frog.—The frog is a device by means of which the rail at the turnout curve crosses the rail of the main track. The frog shown in Fig. 523 is made of rails having the same cross-section as those used in the track. Its parts are as follows: The wedge shaped part *A* is the **tongue,** of which the extreme end *a* is the **point.** The space *b*, between the ends *c* and *d* of the rails, is the **mouth,**

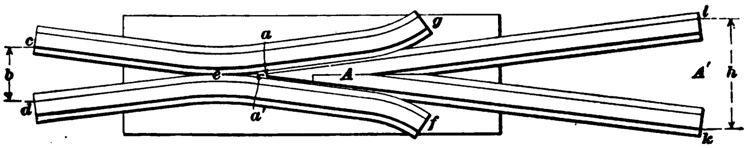


FIG. 523.

and the channel which they form at its narrowest point *e* is the **throat.** The curved ends *f* and *g* are the **wings.**

That part of the frog between *A* and *A'* is called the **heel.** The width *h* of the frog is called its **spread.** Holes are drilled in the ends of the rails *c*, *d*, *k*, and *l* to receive the bolts used in fastening the rail splices, so that the rails of which the frog is composed form a part of the continuous track.

1678. The Frog Point.—The theoretical point of frog *a'* (see Fig. 523) and the actual point *a* are quite dissimilar. The reason for making *a* the point of frog is that if the theoretical and actual point of frog were the same, the point would be so small that the first blow inflicted by a passing locomotive or car would completely destroy it. The frog point is accordingly placed at *a*, where its width is about $\frac{1}{4}$ of an inch.

1679. The Frog Number.—The number of a frog is the ratio of its length to its breadth, i. e., the quotient of its length divided by its breadth.

Thus, in Fig. 523, if the length *a' l*, from point to heel of frog is 5 feet, or 60 inches, and the breadth *h* of the heel is 15 inches, the number of the frog is the quotient of $60 \div 15 = 4$. Theoretically, the length of the frog is the distance from *a* to the middle point of a line drawn from *k* to *l*; practically, we take as the length the distance from *a* to *l*. As it is often difficult to determine the exact point *a* of the frog, a more accurate method of determining the frog number is to *measure the entire length d l of the frog from mouth to heel, and divide this length by the sum of the mouth width b and the heel width h. The quotient will be the exact number of the frog.*

For example, if in Fig. 523, the total length *d l* of the frog is 7 feet 4 inches, or 88 inches, and the width *h* is 15 inches, and the width *b* of the mouth is 7 inches, then the frog number is $88 \div (15 + 7) = 4$. Frogs are known by their *numbers*. That in Fig. 523 is a No. 4 frog.

1680. The Frog Angle.—The **frog angle** is the angle formed by the gauge lines of the rails, which form its tongue. Thus, in Fig. 523, the frog angle is the angle *l a' k*. The amount of the angle may be found as follows: The tongue and heel of the frog form an isosceles triangle (see Fig. 524). By drawing a line from the point *a* of the frog

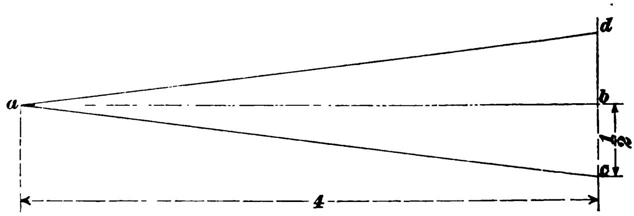


FIG. 524.

to the middle point *b* of the heel *c d*, we form a right-angled triangle, right-angled at *b*. The perpendicular line *a b*,

bisects the angle a, and, by rule **5**, Art. **754**, we have tan $\frac{1}{2}a = \frac{bc}{ab}$. The dimensions of the frog point given in Fig. 524 are not the same as those given in Fig. 523, but their relative proportions are the same, viz., the length is four times the breadth. The length $a\ b = 4$, and the width $c\ d = 1$; hence, $b\ c = \frac{1}{2}$. Substituting these values, we have tan $\frac{1}{2}\ a = \frac{\frac{1}{2}}{4} = \frac{1}{8} = 0.125$. Whence, $\frac{1}{2}\ a = 7°\ 7\frac{1}{2}'$, and $a = 14°\ 15'$; that is, the angle of a No. 4 frog is 14° 15'.

Frog numbers run from 4 to 12, including half numbers, the spread of the frog increasing as the number decreases.

1681. Classification and Description of Frogs.— Frogs, as manufactured to-day, are of two classes, viz., *stiff frogs* and *spring-rail frogs.* Each has advantages peculiar to itself, which specially adapt it to certain situations. **Stiff frogs** contain much less material and require less shop work than spring frogs. For a given angle a stiff frog requires less space, and hence is better adapted to yard work than spring-rail frogs. They are more simply constructed than spring frogs, and can be made at any well-equipped machine shop.

Spring-rail frogs, because of their furnishing an unbroken surface to the wheel treads, are particularly adapted to the heavy traffic of a trunk line.

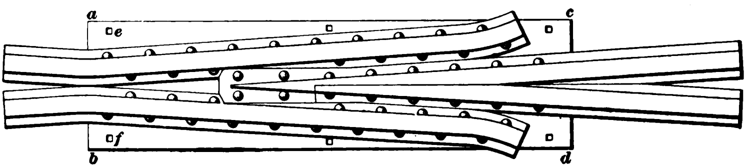


FIG. 525.

Figs. 525 and 526 represent the best types of stiff frogs. The frog shown in Fig. 525 is called a **plate frog.** The rails composing the frog are fastened to a plate of wrought iron or steel $a\ c\ d\ b$ by means of rivets through the rail flanges, as shown in the figure. Square holes e, f are

punched in the plate to receive the railroad spikes, which are driven into the cross-ties supporting the frog, holding it firmly in place. Plate frogs are perfectly rigid, and by many railroad men are considered inferior to the **keyed frog,** shown in Fig. 526, which is somewhat flexible and better

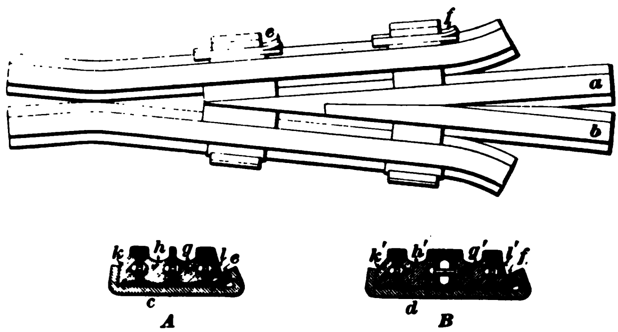


FIG. 526.

suited to yard work where the curves are sharp and the frog angles correspondingly large.

In this frog, the pieces of rails *a* and *b*, forming the point, are dovetailed together and secured by heavy rivets. To retain the full strength and durability of the steel, all the parts are fitted without being heated, excepting the wings, which are bent at a very low heat. Hence, the strength of the rails is in no respect diminished, and the method of securing the parts together has advantages over bolts or rivets passing through the webs or flanges of the rails, as there is nothing which can come in contact with the wheel flanges. From its peculiar construction, it has the same *elasticity* as the rails in the track, which makes it an *easy riding* frog, more durable than a rigid frog, and less liable to injury from uneven ballasting. It presents little obstruction to tamping, and, when fastened into the track with the usual angle splices, it is firm, stable, and free from any tendency to jump or move.

The parts are bound together by heavy wrought-iron clamps *c* and *d*, shown in the cross-sections *A* and *B*, *A* being a cross-section through the first clamp and *B* one

through the second clamp. These clamps are tightened by means of beveled split keys, or wedges, *e* and *f*, the ends of the clamps being bent over a form to an exact angle, at one end to fit the brace blocks *k* and *k'* on the outside of the rail, and at the other end to fit the beveled keys, which are driven into the spaces between the end of the clamp and the smaller brace blocks *l*, *l'*. The keys lie on the flange of the rail, which prevents them from dropping down in case they loosen. The flange way between the frog point and the wing rails is maintained by iron throat-pieces *g*, *h*, *g'*, and *h'*, which fit the rails perfectly, and, extending beyond the point, thoroughly brace and stay it against lateral stresses. After the keys are driven to the extent necessary to bind the parts solidly together, the split ends are spread to prevent the keys from working out.

The throat-pieces, as well as the brace blocks, are effectually prevented from sliding out of their positions. The clamps are firmly secured to the flanges of the rails, and the only movable pieces in the frog are the keys which, being thicker on their lower edge (owing to being beveled unequally), together with the angles of the clamps, prevent the keys from working upwards. Trackmen, when inspecting track, should always examine the frogs, and any key loosened by the wearing of the parts should be tightly driven, and the split end spread open. Unless a key is loose it should never be hammered.

A standard type of a **spring-rail frog** of *keyed pattern* is shown in Fig. 527. For main line tracks, and especially for those sections where the heavy traffic moves principally in one direction, the spring-rail frog is recommended. It gives to the main line the smoothness of an unbroken track; it is simple in its construction, thoroughly substantial, and is placed in position with the least amount of labor.

As shown in the figure, the fixed parts of the *patent keyed spring frog* are bound together by two heavy clamps *a* and *b*, shown in the details *A* and *B*, which are sections through the clamps at *C D* and *E F*. The parts within the clamps are secured by split keys or wedges *c* and *d*. The frog point

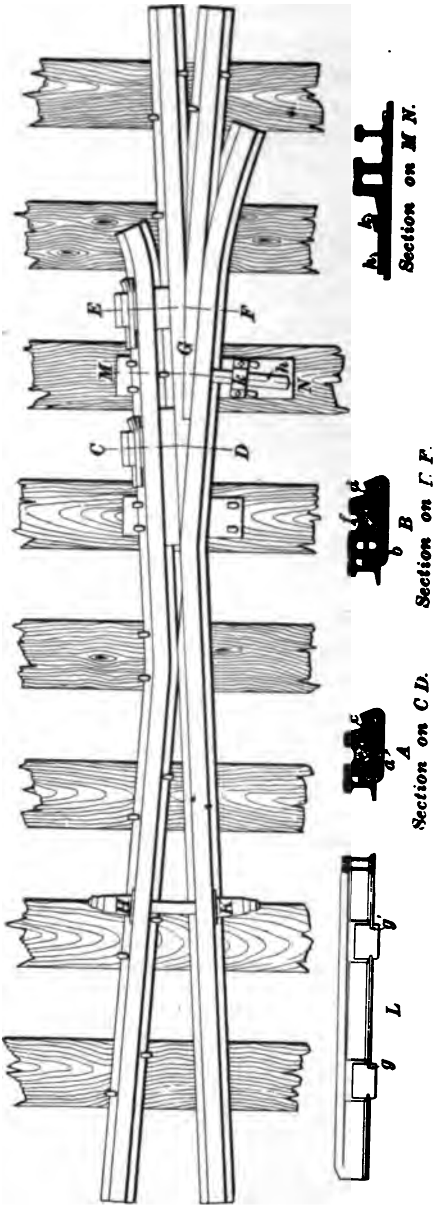


FIG. 527.

G is made of two pieces of steel rail fitted and dovetailed together by machinery, without being heated, and securely riveted together. The flange way between the point and wing rails is maintained by closely fitting iron throat-pieces *e* and *f* (shown in the detail sections *A* and *B*), which are prevented from slipping by rivets and pins through the rails. The clamps have side notches *g* and *g'* at one end (shown in detail at *L*), which engage with notches in the flange at the frog point, and prevent the clamps from slipping down, even if loose. The other end of the clamp is bent over a form to an exact angle to fit the beveled split key, which is driven into the space between the clamp and the block, which is fitted and secured to the side wing rail. When the key is driven, the parts of

the frog are tightly bound together, and the key resting upon the flange of the rail is prevented from working down and loosening. The outer end of the clamp is secured by clips, which are riveted to the flange of the rail.

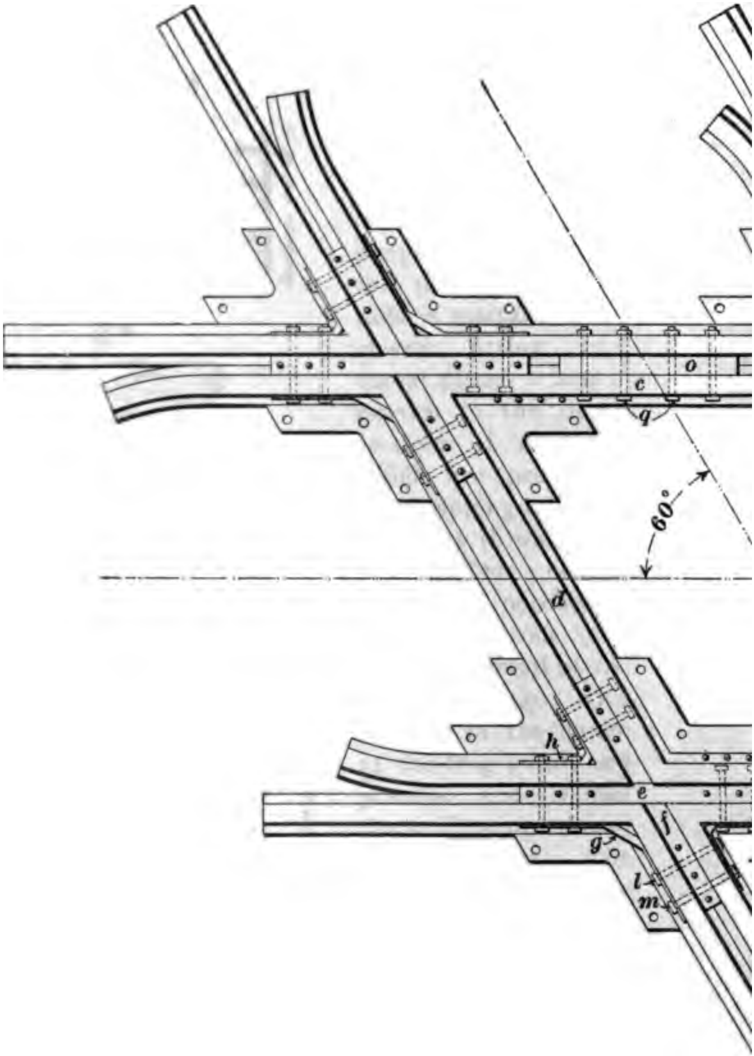
In case the parts of the frog become loosened by wear, they may be tightened by driving the wedge further in and spreading the split ends so as to hold the key firmly in place.

That part of the flange of the spring rail next to the frog point is planed off, allowing the head of the spring rail to lie close to the frog point, forming almost a continuous rail and fully accommodating all classes of wheels passing the frog. Powerful springs *H* and *K* hold the spring rail firmly against the frog point, and the slide arm *h*, which is held in place by the clip *k*, attached to the slide plate (shown in the detail section *M N*), prevents the spring rail from rising up or moving out too far. The usual length of this spring frog for any angle is 15 feet.

1682. Crossing Frogs.—Where one railroad crosses another at grade, frogs of special design, called **crossing frogs,** are required. They are of various patterns, depending upon the angle of the crossing and the importance of the line. In Fig. 528 a cut is given of a *standard crossing*, which embodies the best features as determined by experience.

This crossing is made of the best quality steel rails, fitted with exactness. The points are mitered, dovetailed, welded, or forged out of solid rails, the angle of the crossing and the requirements of the case determining which method is the most practicable. The rails are mounted on strong wrought-iron bed-plates *A*, *B*, etc., to which they are securely riveted through the flanges of the rails. The guard-rails *a*, *b*, *c*, and *d*, inside the intersecting tracks, extend unbroken on all sides, and extend outside the frog points so as to guide the trucks, causing them to pass squarely through the crossing.

At all the angles the flange way is completely filled by wrought-iron throat fillers *e*, *f*, and *c*, which are shaped to exactly fit the rails.



F

replacing frog rigidly in place. A replacing frog is placed in position on both rails, and the car pulled on to the track with a locomotive. Where the trucks are slewed crosswise to the track, the car must be jacked up and the trucks straightened before placing the frogs.

SWITCHES.

1684. Classification of Switches.—Although there have been many different kinds of switches devised, only two of them have ever been in general use; viz., **stub** and **split,** or **point,** switches. Stub switches are now rarely used on first-class roads, even in yards, the split or point switch having entirely supplanted them. It is estimated that 50 per cent. of the derailments on American lines have been directly chargeable to the defects of the stub switch.

The principal defect in the stub switch lies in the open joint at the head-block. In passing over this joint, each wheel delivers a heavy blow on the ends of the rails at the point, which not only batters the rails but also causes a heavy jolt to the car, injurious to the rolling stock and causing much discomfort to passengers. Stub switches are more liable to misplacement than split switches, and there is the constantly recurring need of recutting the ends of the rails at the head-block, to provide for expansion and for the removal of battered ends.

1685. The Stub Switch.—The essential parts of a stub switch are shown at *A* in Fig. 530. The rails *a b* and *c d* are the **switch rails** placed for the turnout track. Their position when placed for the main track is indicated by dotted lines at *e* and *f*. The switch rails are commonly used in lengths of 30 feet, the standard rail length, of which only 22 feet are free to move or slide, the remaining 8 feet being spiked to the ties, as shown in the figure. The moving portions of the switch rails are held in place by rods *g*, *h*, *k*, and *l*, called **switch rods.** These rods keep the switch rails at proper gauge, and serve the purpose of track spikes.

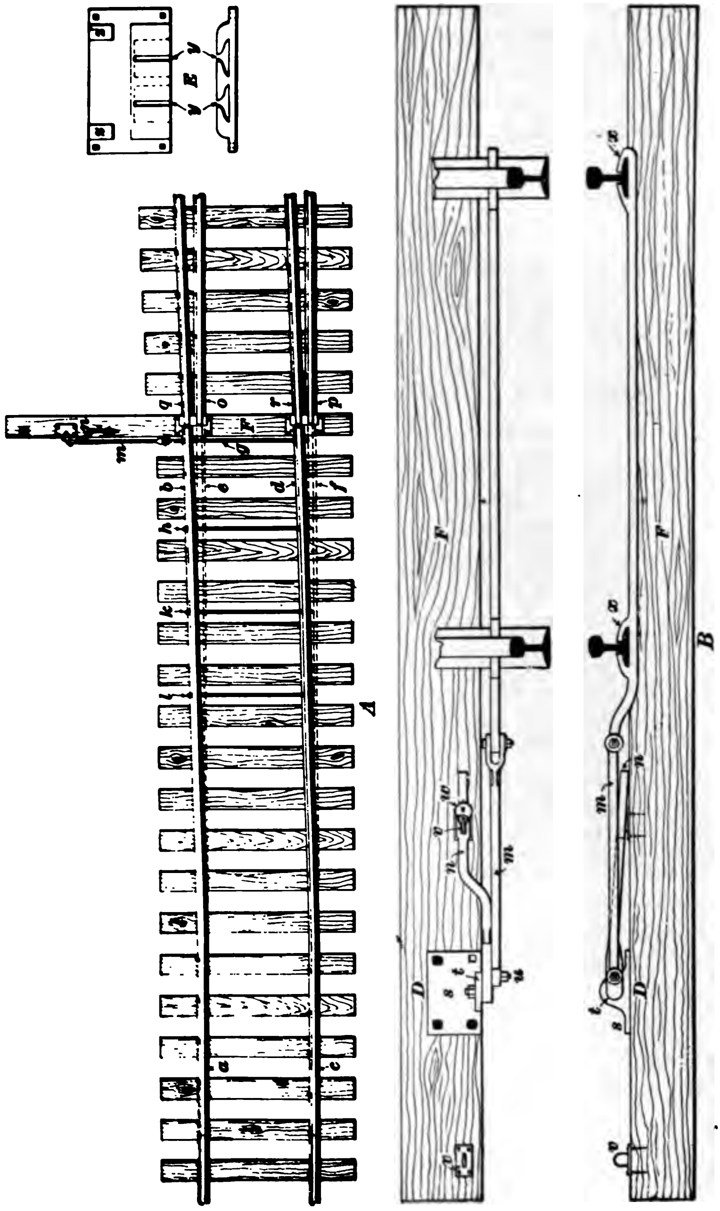


FIG. 530.

The first switch rod g is called the **head rod.** It extends outside the rails, and by means of the **connection rod** m, it is attached to the lever n of the switch stand, by means of which the switch rails are moved from their connection with the main track rails o and p, to a connection with the turnout rails q and r. This movement of the switch rails is termed **throwing the switch.**

The **switch stand,** and connection and head rods of this switch are shown in detail at B. The switch stand D consists of a cast-iron plate s to which is cast a semicircular lug t. A hole in this lug receives a pin, which is attached to the end of the lever n. The connection rod m is attached to the lever by means of the pin u, and is held in place by a nut. The lever handle is slotted, and when the switch is set for either track, the slot fits over a staple v, projecting above the lever far enough to receive a padlock w which locks the switch.

The switch rods clamp the switch rails firmly, as shown at x. The **head chair,** shown at E, is of cast iron, and contains sockets y, y, into which the ends of the main and turnout rails o and q securely fit. The lateral movement of the switch rail is limited by the lugs z and z', which are cast into the chair. The head chair is usually fastened to the headblock with track spikes.

The cross-tie F, which supports the head chairs and switch stand, is called the **head block.** The head block and all other switch ties should be of hard wood—oak preferably. The ties under the switch rails should be of sawed timber, so as to present a smooth even surface for the sliding rails.

This type of switch stand is equally well suited to split switches, and on account of its compactness is especially suited to yard work.

The stub switch is cheaper than the split switch, and for tracks owned by private concerns, it serves very well; but for railroads doing a regular freight and passenger business, it is not only out of date, but should be condemned as unsafe.

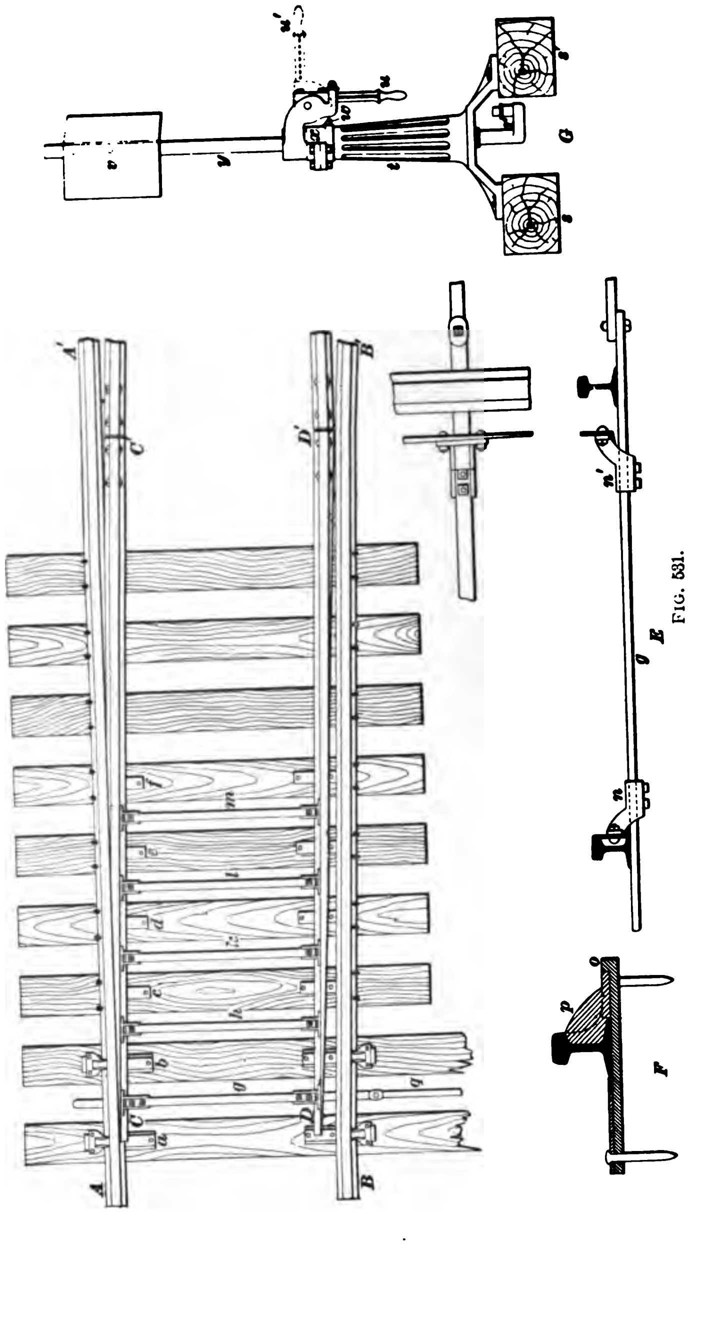


FIG. 531.

1686. Split, or Point, Switches.—The split, or point, switch does away with the open joint at the head block and gives a continuous bearing to the car wheels. The two common types of split switches are shown in Figs. 531 and 532. In Fig. 531, the rails A A' and B B' are called the **stock rails.** In the split switch, the heels and toes of the switch rails are exactly the reverse of those in the stub switch, i. e., the *heels* in the *split switch* are in the places occupied by the *toes* in the *stub switch.* The stock rails are spiked throughout their entire length. The switch rails C C', D D' are usually 15 feet in length for all turnouts excepting those in yards where limited space requires very sharp curves, and switch points 12 feet in length, or even less, are used instead.

The switch rails are usually straight and planed down so as to fit closely to the stock rails for 6 or 7 feet. The points C and D are planed down to a thin edge, the web of the switch rail being grooved so as to fit under the head of the stock rail.

The base of the switch rail is planed so that it fits snugly against the upper part of the base of the stock rail. The extreme points of the switch rails are slightly below the level of the stock rails, so that the wheel treads do not come in contact with them until their size and strength are sufficient to stand the hard pounding which all switches receive.

The slide plates a, b, c, d, e, and f extend under the stock rails and points, and are spiked to the cross-ties. The switch rods g, h, k, l, and m are of wrought iron, and of such dimensions as the size and weight of the rail require. They are fastened to the switch rails in various ways. In Fig. 531, the connection is made by means of cast steel sockets which are bolted to the webs of the rails. The switch rod g, connecting directly with the switch stand, is called the **head rod,** and is shown in detail at E. The cast-steel sockets n and n' are longer, and extend low enough to permit the head rod to pass under the rails, as shown in the detail. The head rod is fastened to each socket with two bolts, while the other switch rods are single bolted.

The stock rails are spiked only on the outsides of the rails, and to prevent the rails from getting out of line, the slide plates are bent upwards at the outside of the rail, forming the lip *o* (see detail at *F*), which holds the rail brace *p* solidly against the stock rail.

The connection rod *q* is fastened at one end to the head rod and at the other end to the crank *r* of the switch stand, shown in detail at *G*. The switch stand rests upon two cross-ties *s* and *s'*, being securely fastened to them either with bolts or track spikes. The switch stand consists of the column-shaped support *t*, the lever *u*, used in throwing the switch, the target *v*, and the crank-shaft *r*.

The target *v* consists of two rectangular pieces of sheet iron fastened to the target rod at right angles to each other. One-half of the target is usually painted *white*, indicating **safety**, and the other half *red*, indicating **danger.** They are so adjusted that an open switch always indicates **danger.**

The lever *u* carries a *cam* or eccentric-shaped disk *w* which, when in the position *u*, fits between lugs *x*; the lugs are bolted to the pedestal *t*, and form a part of the rigid stand. When the lever is in the position *u*, the switch may be locked, holding the switch firmly in place. To throw the switch, raise the lever to the position *u'*. This releases the cam *w* from the lug *x*, and the lever being clamped to the target rod or shaft *y*, any movement of the lever *u* is communicated to the crank *r*, which, by means of the connection rod *q*, acts directly upon the switch rails.

The throw of the switch is from 4½ to 5 inches. The rail braces *p* are usually of forged steel, though some are still made of cast iron.

1687. Safety Switches.—When a train passes from the main track to the side track, it necessarily passes the points of the switch first. Such a switch is called a **facing switch.** When, on the other hand, a train passes from the side track to the main track, it passes the frog first. Such a switch is called a **trailing switch.**

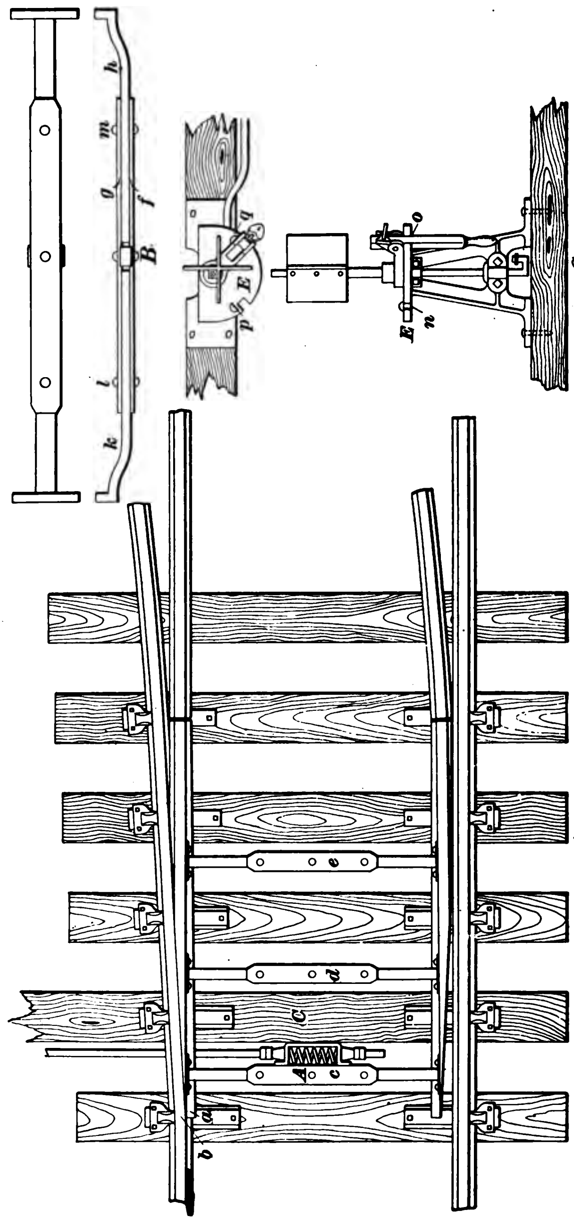


FIG. 532.

William Lorenz, chief engineer of the Philadelphia and Reading Railroad, has the credit of designing a self-acting switch, which is provided with a powerful spring that holds the switch points firmly against the stock rail, thus keeping the main track constantly unbroken. With the switch points in this position, a train can make a trailing switch, the wheel flanges forcing the switch open as they pass from the side to the main track. As the spring is constantly acting, each wheel throws the switch, which instantly resumes its position for the main track.

Such a switch is called a **Lorenz,** or **safety switch,** and is shown in Fig. 532. With the exception of the spiral spring *A*, which is attached to the head rod and holds the switch point *a* against the stock rail *b*, this switch is similar to that shown in Fig. 531.

The switch rods *c*, *d*, and *e*, instead of being single rods with arms at their ends for attaching them to the switch rails, as in Fig. 531, have a trussed center piece, shown in detail at *B*, composed of two bars *f* and *g*, riveted together and leaving between them just space enough to allow the ends of the arms *h* and *k* to move as the switch is thrown from one side of the track to the other, the arms pivoting on the rivets *l* and *m* at the end of the center piece.

This form of switch rod combines flexibility with great strength, insuring easy movement to the switch and great resistance to the severe stresses which are continually brought to bear against it.

The switch rods are bent downwards near the arms, bringing them nearly on a level with the top of the tie, where they are less exposed to injury from derailed cars or from broken parts of the cars, such as brake rods or beams, which dragging on the ties frequently catch in switch rods, doing much harm.

The safety switch, shown in Fig. 532, is of a pattern commonly used in yards and terminals. The switch points vary in length from 7½ feet to 12 feet, the former fitting all frog numbers as high as 7, and the latter serving for frogs of all numbers.

The advantages of this switch are its compactness, requiring little more than half the space of an ordinary switch; lightness, which insures easy handling, and its adaptation to sharp curves which abound in yards and terminals. The short points permit of trailing switches equally as well as facing switches, as the planed portion of the points is short, and, consequently, carries a much shorter proportion of the wheel base of an engine or car than the switch of the standard length. The short points also require lighter springs than the standard lengths, and are much easier cleared of snow. The details of the switch are practically the same as those of the switch shown in Fig. 531, which were fully described. A common yard stand suitable for this switch is shown in both plan and elevation at *C*. The target is about 4 feet above the ground, and is provided with an attachment for signal lamp. The lever is hinge-jointed, and in throwing the switch, the lever is brought into a horizontal position, resting on the semicircular iron latch plate *E*. In the edge of this plate are two slots *n* and *o*, into which the lever hinges after the switch is thrown. Lugs *p* and *q* at the sides of the slots, limit the lateral movement of the lever. The switch stand is secured to the head-block by either bolts or track spikes, usually the latter.

1688. Three-Throw Switches.—A cut of a three-throw, or double-throw, switch is given in Fig. 533. The type is that of the ordinary stub switch, except that the moving or switch rails serve two turnout tracks instead of but one. The head chair *A* is usually of cast iron and contains sockets *a*, *b*, and *c* (see detail *B*) for the fixed rails *d*, *e*, and *f*.

The switch rails *g* and *h* have a total lateral movement at the head chairs of from 10 to 12 inches, depending upon the dimensions of the rails. Their lateral movement is fixed by the lugs *k*, *k* on the head chairs.

The switch stand is shown in elevation at *C*, and in plan at *D*. The three positions of the switch are fixed by the slots *l*, *m*, and *o* in the latch plate into which the switch lever hinges.

A more comprehensive idea of a double-throw switch may be obtained from the detail given at *E*, which shows to a re-

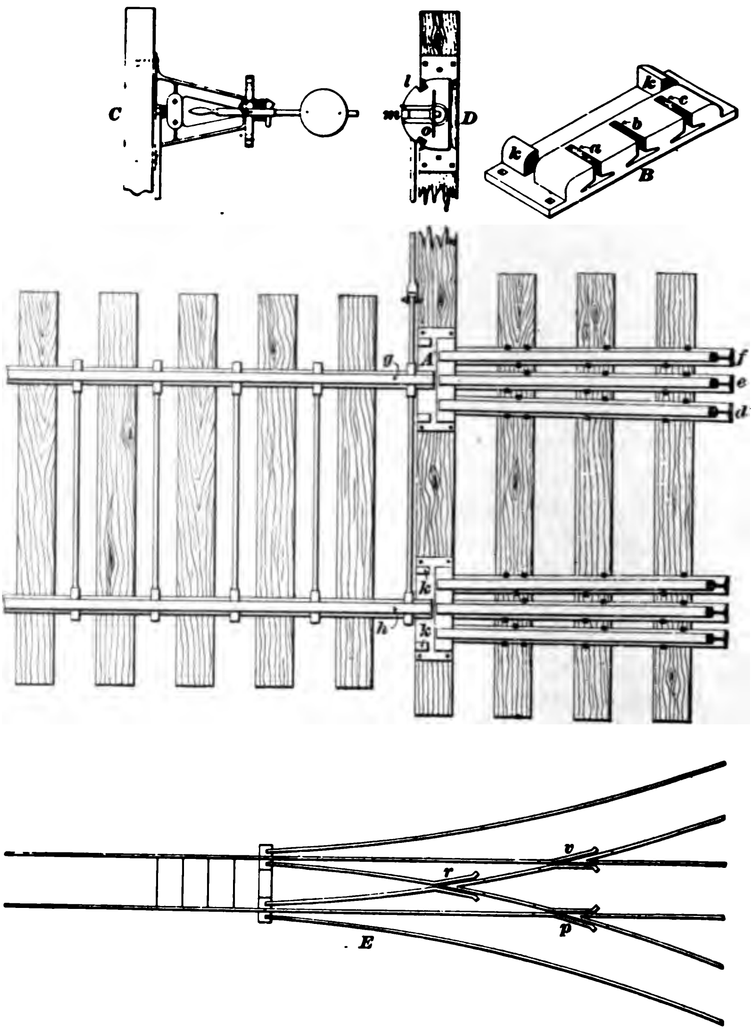


FIG. 533.

duced scale the switch and both turnout curves with **main** rail frogs *p* and *v*, and the **crotch frog** *r*, by means of **which**

the outer rails of the turnout curves cross each other. The turnout curves of a double-throw switch are usually of the same degree, which brings the crotch frog in the middle of the main track.

The defects of the stub switch already described should prevent its use in the main track at yards, and at terminals where trains move slowly, as well as at intermediate points where trains run at top speed.

A double-throw **split switch** has been invented and used in a limited way, and though a perfect switch so far as mechanism is concerned, it is much more expensive and complicated than a double-throw stub switch, and is not enduring.

The object of the double-throw switch, viz., economy of space, is practically attained by substituting two single split

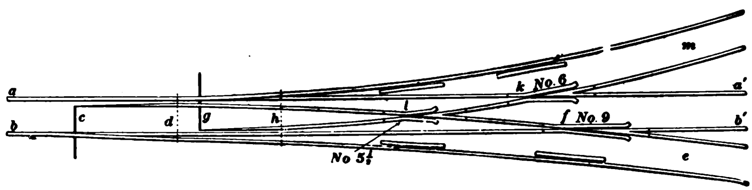


FIG. 534.

switches, placed as close together as is consistent with their safe operation. Such an arrangement is shown in Fig. 534, in which *a a'* and *b b'* are the rails of the main track. A 7° 30' turnout curve *c e* is laid out to the right of the main track. This calls for a head block at *c* and a No. 9 frog at *f*.

A 17° turnout curve *g m* is next laid out to the left of the main track, with its P. C. located so as to bring the head block *g* of the second switch far enough from the heel *d* of the first switch to afford sufficient room for operating the second switch. This calls for a No. 6 frog at *k* and a No. 5½ crotch frog at *l*.

1689. Derailing Switches.—A **derailing switch** is a device for derailing cars, and so preventing them from accidentally running out of the siding on the main track.

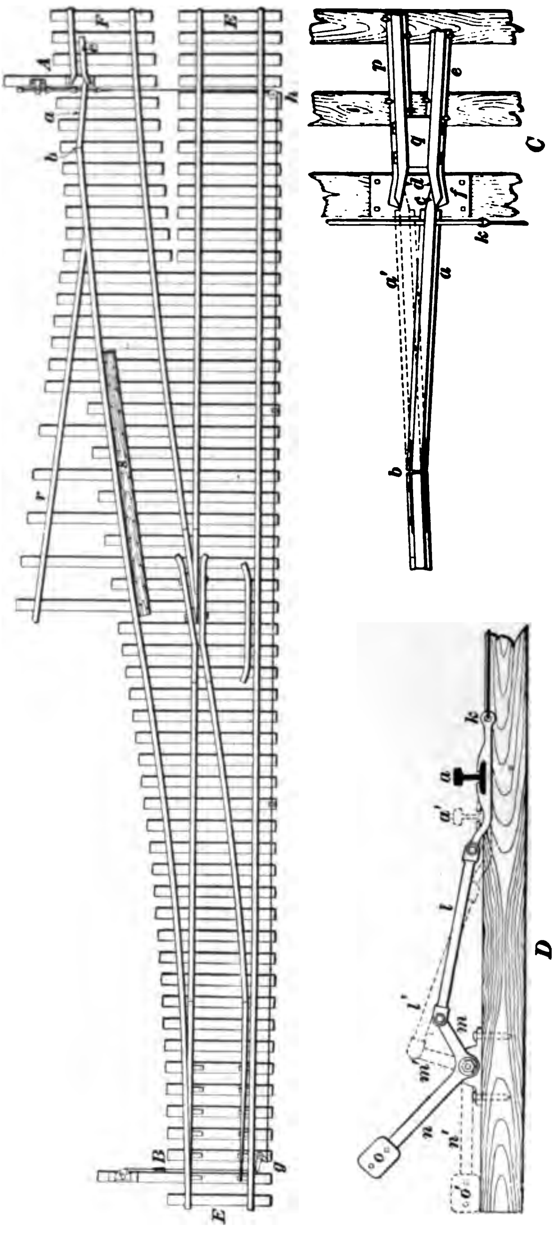


FIG. 585.

They are, of course, needed only for sidings built with grades descending towards the switch.

An effective type of a derailing switch is shown at *A* in Fig. 535. It consists of a single switch rail *a*, which is hinged at the rail joint *b*. The switch point *c* is beveled, as shown in the detail at *C*. When the switch is closed, this beveled switch point rests against the outside rail of the siding, which is bent at an angle corresponding to the bevel of the switch point and shown at *d*, forming a **lap switch.** When the switch is open, the switch point rests against the guard rail *e*, the end of which is beveled to form a seat for the switch point. The beveled ends of both track and guard rail rest upon a wrought-iron head chair *f*, shown in detail at *C*, upon which the switch point slides.

This switch is connected with and operated by the movement of the *main line switch B*. The figure shows the switch set for the *main line*, and the derailing switch set to throw from the track a car moving out of the siding.

The derailing switch is operated as follows: A bell-crank *g* is pivoted to a cross-tie, with one end of the crank attached to the *head rod* of the switch *B*. To the other end of the crank is attached a strong steel wire which extends to a sheave *h*, directly opposite the derailing switch *A*, and thence to an eye *k*, as shown in detail at *C* and *D*, in the end of the head rod. This wire is kept *taut*, so that any movement of the switch *B* is communicated directly to the switch rail *a*. The connection rod *l* is attached to the short arm *m* of the switch lever; and when the switch is set for the main line *E E*, as shown in the figure, the resulting stress in the wire is transmitted to the short arm *m* of the derailing switch lever; the long arm of the lever which carries the weight *o* is then brought into the position *n*, and the switch rail or point takes the position *a* (see detail *C*), leaving the derailing switch open and protecting the main track from runaway cars.

When, on the other hand, the switch is placed for the siding *E F*, the tension on the wire is relaxed and the long arm *n* of the derailing switch lever, being acted upon by the

weight *o*, is made to take the position *n'*, and the short arm of the lever, the position *m'*. This movement is transmitted by the connection rod to the switch rail, which takes the position *a'* (see detail *C*), securely closing the switch. The guard rail *c* is secured to the main rail *p* by two heavy bolts, the space between them being maintained by a cast-iron throat filler *q*. Near the derailing switch, a guard rail *r* is placed, diverging from the outside rail, the object of which is to prevent derailed cars from running on to the main line. A heavy plank *s* is spiked to the ties close to the outside rail to prevent any derailed trucks from turning up the rails.

1690. Automatic Turnouts.—For **dummy** or **street car roads** using a light **T** rail, the automatic switch

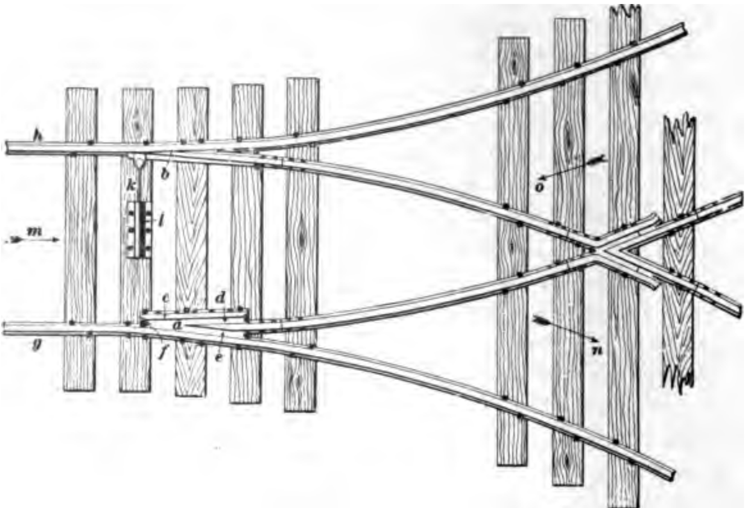


FIG. 536.

shown in Fig. 536 may be used on turnouts, or passing tracks, to great advantage. There are two switch points *a* and *b*, one of which, *a*, is *rigid*, forming a combination of frog and switch point. It consists of a guard rail *c*, two throat fillers *d* and *e*, and the switch point *a*. The throat fillers between the switch point and the head block unite, forming a single filler, which is grooved at *f*. When

approaching or leaving the switch, the wheel flange enters this groove, bringing the wheel tread safely upon the stock rail *g*.

In America, at least, it is the universal custom for cars approaching a passing track to take the right-hand track in the direction indicated in the figure by the arrows *m* and *n*. Accordingly the switch is always set for the right-hand track, the switch point *b* being held firmly against the stock rail *h* by means of the iron rod *k*, which is acted upon by a powerful spring confined in the shell *l*. This shell is spiked to the head block between the rails, as shown in the figure, and hence is not an obstruction to travel, as it would be if placed outside the rails, and it is also comparatively safe from injury from the wheels of heavy trucks and drays.

A car moving in the opposite direction, as indicated by the arrow *o*, throws the switch automatically. As the wheel flanges come in contact with the switch rail *b*, the spiral spring which holds the switch rail in place yields to the pressure, and the switch opens, allowing the car to pass from the siding to the main track. The wheel flanges, after passing the switch point *a*, enter the groove *f*, before mentioned, and the wheel treads pass safely on to the stock rail *g*. As the spring is constantly acting, each wheel throws the switch, which closes the instant the wheel flange passes the point.

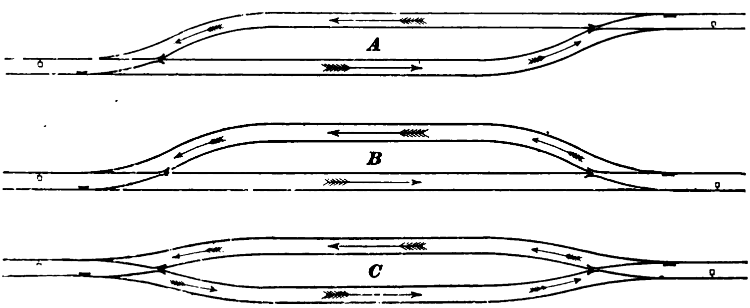


FIG. 537.

There are three forms of turnouts, or passing tracks, in general use; they are shown in Fig. 537, at *A*, *B*, and *C*,

the arrows indicating the direction in which cars enter and leave the turnout. It will be seen that some one of these three forms of passing tracks will meet practically any given situation. That shown at *B* is particularly suited to track laid along the side of a street or highway, which may be widened at the points requiring passing tracks. The form shown at *C* should always be adopted for tracks laid on the center line of streets. The extra room required for passing tracks is equally distributed on both sides of the main center line of the street, so that there will be the least possible encroachment upon the space left for vehicles.

1691. Y Tracks.—The form of turnout shown in Fig. 538 is called a **Y**. It is used as a substitute for a

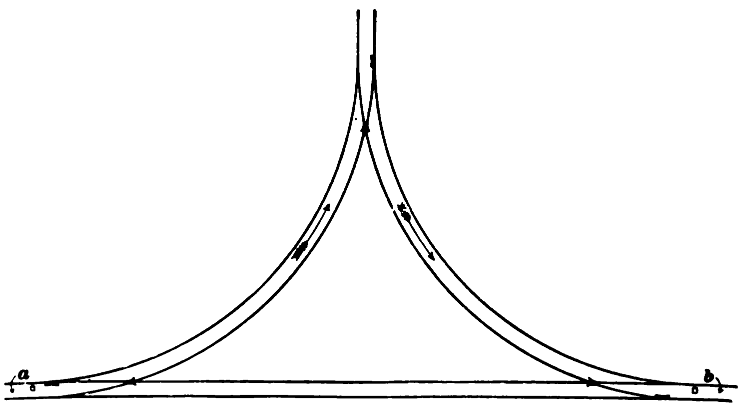


FIG. 538.

turntable. Sometimes the switches are automatic, as shown in the figure, in which case all locomotives must enter the **Y** from the same end, viz., at *a*, and leave at *b*. Usually, however, the switches are operated by hand levers and the **Y** is entered from both directions. One special advantage of a **Y** track is that both engine and train may be turned together, and where favorably situated, they are much used in shifting light trains which are run at frequent intervals for the accommodation of suburban travel.

1692. The Parts of a Turnout.—The several parts of a turnout are represented in Fig. 539. The distance *p f* from the P. C. of the turnout curve to the point of frog is called the **frog distance.** The frog number and frog angle we have already defined. The radius *c o* of the turnout curve, the frog distance, the frog angle, and the frog number bear certain relations to each other, which are expressed by the following formulas:

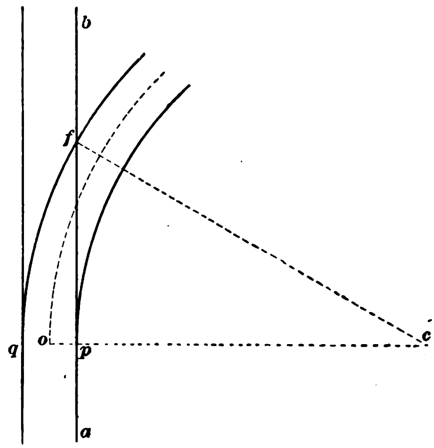


FIG. 539.

Tangent of half frog angle = gauge ÷ frog distance. **(114.)**

Frog number = $\sqrt{\textit{radius } c\, o \div \textit{twice the gauge.}}$ **(115.)**

Frog number = half the cotangent of half the frog angle. **(116.)**

Radius c o = twice the gauge × square of the frog number. **(117.)**

Radius c o = (frog distance p f ÷ sine of frog angle) − ½ the gauge. **(118.)**

Radius c o = gauge ÷ (1 − cosine of frog angle) − ½ the gauge. **(119.)**

Frog distance p f = frog number × twice the gauge. **(120.)**

Frog distance p f = gauge p q ÷ tangent of half the frog angle. **(121.)**

Frog distance p f = (radius c o + half the gauge) × sine of frog angle. **(122.)**

Middle ordinate (approximate) = ¼ the gauge. **(123.)**

Each side ordinate (approximate) = $\frac{3}{4}$ *the middle ordinate* = $\frac{3}{16}$ *(or .188) of the gauge.* **(124.)**

Switch length approximate =

$$\frac{\textit{throw in feet} \times 10{,}000}{\textit{tan deflection for chords of 100 ft. for radius r o of turnout curve.}}$$ **(125.)**

The tangent deflection may be obtained from the table of Tangent and Chord Deflections.

TABLE 35.

TURNOUTS FROM A STRAIGHT TRACK.

Gauge, 4 feet 8½ inches. Throw of Switch, 5 inches.

Frog Number.	Frog Angle.	Turnout Radius.	Degree of Turnout Curve.	Frog Distance.	Middle Ordinate.	Side Ordinate.	Stub Switch Length.
	° ′	Feet.	° ′	Feet.	Feet.	Feet.	Feet.
12	4 46	1,356	4 14	113.0	1.177	.883	34
11½	4 58	1,245	4 36	108.3	1.177	.883	32
11	5 12	1,139	5 02	103.6	1.177	.883	31
10½	5 28	1,038	5 31	98.9	1.177	.883	29
10	5 44	942	6 05	94.2	1.177	.883	28
9½	6 02	850	6 45	89.5	1.177	.883	27
9	6 22	763	7 31	84.7	1.177	.883	25
8½	6 44	680	8 26	80.0	1.177	.883	24
8	7 10	603	9 31	75.3	1.177	.883	22
7½	7 38	530	10 50	70.6	1.177	.883	21
7	8 10	461	12 27	65.9	1.177	.883	20
6½	8 48	398	14 26	61.2	1.177	.883	18
6	9 32	339	16 58	56.5	1.177	.883	17
5½	10 24	285	20 13	51.8	1.177	.883	15
5	11 26	235	24 32	47.1	1.177	.883	14
4½	12 40	191	30 24	42.4	1.177	.883	13
4	14 14	151	38 46	37.7	1.177	.883	11

The switch lengths in the above table merely denote the *shortest* length of *stub switch* that will at the same time form part of the turnout curve, and give 5 inches throw. *Point* or *split switches* require a throw of not more than 3½ inches, though many have a throw of 5 inches, with an equal space between the gauge lines at the heel. The heels of a split switch, which occupy the same position as the toes of a stub switch, should be placed at the point where the tangent deflection or offset is 5 inches. The point where the tangent deflection is but 4½ inches will answer for many rail sections, but for those above 65 lb. per yard, 5 inches should be taken.

In the table of Tangent and Chord Deflections, tangent deflections for chords of 100 feet are given for all curves up to 20°, and for a curve of higher degree, the tangent deflection may be found by applying formula **93,** Art. **1255,**

$$tan\ deflection = \frac{c^2}{2R}.$$

In complicated track work where space is limited, curves must be chosen to meet the existing conditions, and not with reference to particular frog angles, in which case the frogs are called special frogs, and are made to fit the particular curve used. The determination of the frog distance, switch length, and frog angle may be understood by referring to Fig. 540.

Let the main track $a\,b$ be a straight line; the gauge $p\,q =$ 4 feet 8½ inches ($=4.71$ feet); the degree of the turnout curve $=13°$; the chord $q\,d = 100$ feet; $c\,d =$ the tangent deflection of the chord $q\,d$, and $p\,f =$ the frog distance. From the table of Tangents and Chord Deflections, we find the tangent deflection for a chord 100 feet long of a 13° curve is 11.32 feet.

Then, from Fig. 540, we have the proportion (see Art **1256**)

$$c\,d : e\,f :: \overline{q\,c}^2 : \overline{q\,e}^2.$$

Now, in curves of large radius $q\,c$ and $q\,d$ are assumed to be equal. Also, $q\,e = p\,f$, the frog distance, and substituting these equivalents, we have the proportion

$$c\,d : e\,f :: \overline{q\,d}^2 : \overline{p\,f}^2.$$

Substituting the above given quantities in the proportion, we have

$$11.32 : 4.71 :: 100^2 : \overline{pf}^2;$$

whence, $$\overline{pf}^2 = \frac{100^2 \times 4.71}{11.32}, \text{ and}$$

frog distance $pf = 64.5$ feet.

If the space between the gauge lines of the rails at the heels of a split switch be taken at 5 inches = 0.42 of a foot, the distance from the P. C. of the turnout curve to the heel of the switch may be found as follows:

In Fig. 540, let h, the tangent offset at the heel of the switch = 0.42 of a foot, and we have the proportion

$$cd : h :: \overline{qd}^2 : \overline{qh}^2,$$

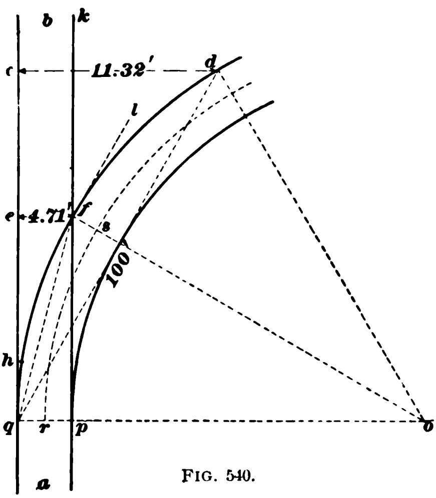


FIG. 540.

and substituting known values, we have

$$11.32 : 0.42 :: 100^2 : \overline{qh}^2;$$

whence, $$\overline{qh}^2 = \frac{10{,}000 \times 0.42}{11.32} = 371.02, \text{ and}$$

$$qh = 19.26 \text{ feet.}$$

This locates the heel of a *split switch* and the toe of a ***stub*** *switch.*

The *frog angle* is the angle kfl (see Fig. 540) formed by the gauge line of the main rail fk and the tangent to the outer rail qf of the turnout curve at the point where the two rails intersect. This angle is equal to the central angle qof. The arcs qf and rs are assumed to be of the same length. The turnout curve being 13°, the central

angle for a chord of 1 foot is $\frac{13 \times 60}{100} = 7.8'$, and the central angle for 64.5 feet, the *frog distance*, is $7.8' \times 64.5 = 8^\circ\ 23'$, the frog angle for a 13° curve. By this process the frog distance, switch length, and frog angle may be calculated for curves of any radius.

1693. To Lay Out a Turnout from a Curved Main Track.—There are two cases:

Case I.—When the two curves deflect in opposite directions, illustrated by Fig. 541, and

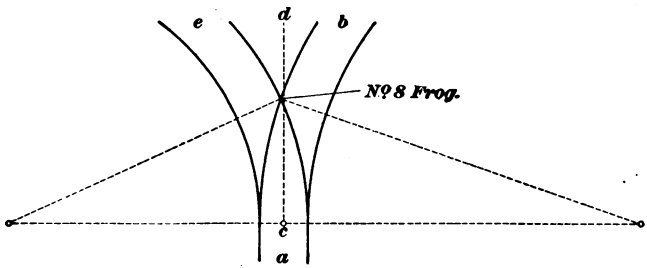


FIG. 541.

Case II.—When the two curves deflect in the same direction, illustrated in Fig. 542.

In Fig. 541, the curve *a b* is 3° 30′, and it is proposed to use a No. 8 frog. By reference to Table 35, we find that the degree of curve corresponding to a No. 8 frog is 9° 31′. Accordingly, we use a turnout curve *a e*, whose degree when added to the degree of curve of the main track shall equal the degree required for a No. 8 frog, i. e., we use a 6° turnout curve, which is within one minute of the required

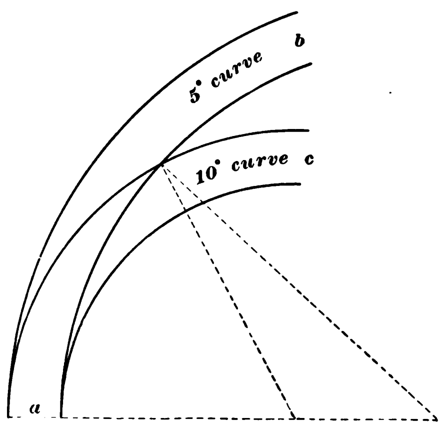


FIG. 542.

degree, and close enough for practical purposes. From our knowledge of tangent and chord deflections we know that for curves of moderate radii, i. e., from 1° up to 12°, the tangent deflections or offsets increase as the degree of the curve. That is, the tangent deflection of a 2°, 4°, and 6° curve is two, four and, six times, respectively, that of a 1° curve. In the accompanying figures illustrating the location of frogs and switches, each curve is represented by two lines indicating the rails, whereas only the center lines of the curves are run in on the ground. In Fig. 541, the line *c d* is tangent to the center lines of the curves. These center lines do not appear in the cut.

Now, if, in Fig. 541, a tangent *c d* be drawn at *c*, the point common to the center lines of the curves, the sum of the deflections of both curves from the common tangent will be equal to the tangent deflection of a 9° 30′ curve from a straight line.

Accordingly, to find the frog distance for a 6° turnout curve from a 3° 30′ curve, the curves being in opposite directions, as shown in Fig. 541, we find the tangent deflection of a 9° 30′ curve for a chord of 100 feet. This deflection is 8.28 feet (see table of Radii and Deflections). Assuming the gauge of track to be standard, viz., 4 ft. 8½ in. = 4.71 ft., and denoting the required frog distance by x, we have the following proportion:

$$8.28 : 4.71 :: 100^2 : x^2;$$

whence, $$x^2 = \frac{10,000 \times 4.71}{8.28} = 5.688.4, \text{ and}$$

frog distance $x = 75.42$ feet.

We use the tangent deflection for a 9° 30′ curve, which is practically the same as for a 9° 31′ curve, and so save the labor of a calculation, which will not appreciably affect the result.

We locate the heel of the switch in the same way, using for the second term of the proportion 0.42 foot, the distance between the gauge lines at the heel, instead of 4.71 feet, the gauge of the track.

In Fig. 542, which comes under Case **II,** both curves deflect in the same direction, and the rate of their deflection from each other is equal to the rate of the deflection of a curve whose degree is equal to the difference of the degrees of the two curves from a tangent.

Let the main track curve *a b* be 5°, and the turnout curve *a c* be 10°. Then the rate of deflection or divergence of the 10° curve from the 5° curve is equal to the divergence of a (10° − 5°) 5° curve from a straight track or tangent.

Accordingly, we find, in the table of Radii and Deflections, the tangent deflection for a 5° curve for a chord of 100 feet = 4.36 feet. Denoting the required *frog distance* by x, we have the following proportion:

$$4.36 : 4.71 :: 100^2 : x^2;$$

whence, $$x^2 = \frac{10{,}000 \times 4.71}{4.36} = 10{,}802.8, \text{ and}$$

frog distance $x = 103.9$ feet.

Distances are not calculated nearer than to tenths of feet.

1694. How to Lay Out a Switch.—In laying out a switch, locate the frog so as to cut the least possible number of rails. Where there is some latitude in the choice of location, the P. C. of the turnout curve can be located, so as to bring the frog near the end of a rail.

To do this, take from Table 35 the frog distance corresponding to the number of the frog to be used. Locate approximately the P. C. of the turnout curve, and measure from it along the main track rail the tabular frog distance. If this brings the frog point near the end of the rail, the P. C. of the turnout curve may be moved so as to require the cutting of *but one* main track rail. Measure the total length of the frog and deduct it from the length of the rail to be cut, marking with red chalk on the flange of the rail the point at which the rail is to be cut. Measure the width of the frog at the heel and calculate the distance from the heel to the theoretical point of frog. For example, if the width of the frog at the heel is 8½ inches, and a No. 8 frog

is to be used, the theoretical distance from the heel to the point of frog is $8.5 \times 8 = 68$ inches = 5 feet 8 inches. Measure off this distance from the point marking the heel of the frog. This will locate the point of frog, which should be distinctly marked with red chalk on the flange of the rail. It is a common practice to make a distinct mark on the web of the main track rail, *directly opposite* to the point of frog. This point being under the head of the rail, it is protected from wear and the weather. The P. C. of the turnout curve is then located by measuring the frog distance from the point of frog. From Table 35 we find the frog distance for a No. 8 frog is 75.3 feet, and the switch length, i. e., the distance from the P. C. of the turnout curve to the heel of the split switch or toe of the stub switch, is 22 feet.

If a *stub switch* is to be laid, make a chalk mark on both main track rails on a line marking the center of the head block. A more permanent mark is made with a center punch. Stretch a cord touching these marks, and drive a stake on each side of the track, with a tack in each. This line should be at right angles to the center line of the track, and the stakes should be far enough from the track as not to be disturbed when putting in switch ties. Next, cut the switch ties of proper length; draw the spikes from the track ties, three or four at a time, and remove them from the track, replacing them with switch ties, and tamping them securely in place. When all the long ties are bedded, cut the main track rail for the frog, being careful that the amount cut off is just equal to the length of the frog. If, by increasing or decreasing the length of the lead 5 per cent. you can avoid cutting a rail, do not hesitate to do so, especially for frogs above No. 8.

Use full length rails (30 feet) for moving or switch rails, and be careful to leave a joint of proper width at the head chair. Spike the head chairs to the head block so that the main track rails will be in perfect line. Spike from 8 to 10 feet of the switch rails to the ties, and slide the cross rods on to the rail flanges, spacing them at equal intervals.

The cross rods are placed between the switch ties, which should not be more than 15 inches from center to center of tie. The switch ties, especially those under the moving rails, should be of *sawed oak timber*. Southern pine is a good second choice. Attach the connection rod to the head rod and to the switch stand. With these connections made, it is an easy matter to place the switch stand so as to give the proper throw of the switch.

It is common practice to fasten the switch stand to the head block with track spikes, but a better fastening is made with bolts. The stand is first properly placed and the holes marked and bored, and the bolts passed through from the under side of the head block. This obviates all danger of movement of the switch stand in fastening, which is liable to occur when spikes are used, and insures a *perfect throw*.

The use of track spikes is quite admissible when holes are bored to receive them, in which case a half-inch auger should be used for standard track spikes. The switch stand should, when possible, be placed facing the switch, so as to be seen from the engineer's side of the engine—the right-hand side.

Next stretch a cord from *a*, Fig. 543, a point on the outer main track rail opposite the P. C. of the turnout curve, to *b*, the point of the frog. This cord will take the position of the chord of the arc of the outer rail of the turnout curve. Mark the middle point *c* and the quarter points *d* and *e*. Whatever the degree of the turnout curve, the distance from the middle point *c* of the chord to the arc *a b* is 1.18 feet, and the distances from the quarter points *d* and *e* are .88 foot; hence, at *c* lay off the ordinate 1.18 feet, and at both *d* and *e* the ordinate .88 foot, three-quarters of the middle ordinate. These offsets will mark the gauge line of the rail *a b*. Add to these offsets the distance from the gauge line to outside of the rail flange,

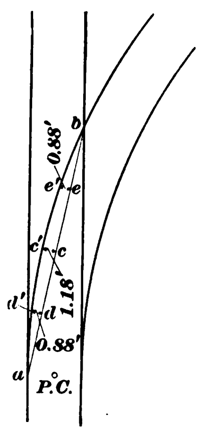


FIG. 543.

and mark the points on the switch ties. Spike a lead rail to these marks and place the other at easy track gauge from it. Spike the rails of the turnout as far as the point of frog to exact gauge, unless the gauge has been widened owing to the sharpness of the curve. Beyond the point of frog the curve may be allowed to vary a little in gauge to prevent a kink showing opposite the frog. In case the gauge is widened at the frog, increase the guard rail distance an equal amount. For a gauge of 4 feet 8½ inches, place the side of the guard rail which comes in contact with the car wheels at 4 feet 6¾ inches from the gauge line of the frog. This gives a space of 1¾ inches between the main rail and the guard rail.

In case the gauge is widened ¼ or ½ inch, increase the guard rail distance an equal amount.

When the turnout curve is very sharp, it will be necessary to curve the switch rails, to avoid an angle at the head block. The lead rails should be carefully curved before being laid, and great pains taken to secure a perfect line.

If a *point*, or *split*, *switch* is to be laid, the order of work is nearly the same. The same precautions must be taken to avoid the unnecessary cutting of rails, with the additional precaution of keeping the switch points clear of rail joints, as the bolts and angle splices will prevent the switch points from lying close to the stock rails. As already stated, these conditions can usually be met where there is some range in the choice of the location of the switch. Where there is none, the main track rails must be cut to fit the switch.

Having located the point of frog, the P. C. of the turnout curve, and the heel line of the switch, measure back from the heel line a distance equal to the length of the switch rails, and place on the flange of each rail a chalk mark to locate the ends of the switch points. This will also locate the head block. Prepare switch ties of the requisite number and length, and place them in the track in proper order. As in

the case of stub switches, see to it that all long switch ties are in place before cutting the rail for placing the frog; also, that the ends of the lead rails, with which the switch points connect, are exactly even; otherwise the switch rods will be skewed, and the switch will not work or fit well. Fasten the switch rods in place, being careful to place them in their proper order, the head rod being No. 1. Each rod is marked with a center punch, the number of the punch marks corresponding to the number of the rod.

Couple the switch points with the lead rails and place the sliding plates in position, securely spiking them to the ties. Connect the head rod with the switch stand, and close the switch, giving a clear main track.

Adjust the stand for this position of the switch, and bolt it fast to the head block. Next, crowd the stock rail against the switch point so as to insure a close fit, and secure it in place with a rail brace at each tie; then continue the laying of the rails of the turnout.

If there is no engineer to lay out the center line of the turnout, the section foreman can put in the lead from ordinates, as explained in Fig. 543. In modern railroad practice, however, most track work is done under the direction of an engineer, in which case the center line of the turnout is located with a transit. This ensures a correct line and expedites work. For ordinary curves, center stakes at intervals of 50 feet are sufficient, excepting between the P. C. of the turnout and the point of frog, where there should be a center stake at each interval of 25 feet. Place a guard rail opposite the point of frog on both main track and turnout. The guard rail should be 10 feet in length; this is an economical length for cutting rails, as each full-length rail makes three guard rails.

Two styles of guard rails are shown in Fig. 544. That shown at *B* is in general use, but the style shown at *A* is growing in favor.

The latter is curved throughout its entire length. At its middle point *a*, directly opposite the point of frog, the

guard rail is spaced 1¾ inches from the gauge line of the turnout rail *b c*. From this point the guard rail diverges in both directions, giving at each end a flange-way of 4 inches. This allows the wheels full play, excepting at the point of

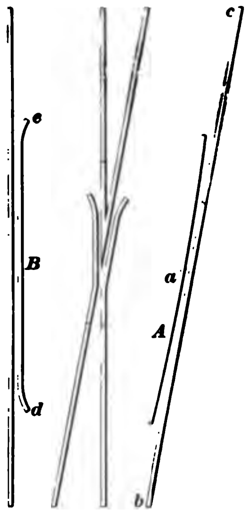


FIG. 544.

frog, where the guard rail is exactly adjusted to the track gauge, and holds the wheels in true line, preventing them from *climbing* or *mounting* the frog. The style of guard rail shown at *B*, though still much used, has two objectionable features, viz., first, the abruptly curved ends *d* and *e* often receive an almost direct blow from the wheel flanges, which causes a car to lurch violently; and second, the flange-way of uniform width, though proper for the main track when straight, as in Fig. 544, is unsuited for sharp curves on either a main track or a turnout, as it compels the wheels to follow a curved line; whereas, the normal position of the wheel base of each truck is that of a chord of, or a tangent to, the curve. These two defects alone produce what is known as a *rough-riding* frog, even though the frog is well lined and ballasted.

It is customary to bend the stock rail with a rail bender in the proportion of about 1 to 40, placing the angle about 10 inches back from the switch points, so that the beveled points will lie snugly against the stock rail. Exception to this rule is found in the practice of the Philadelphia and Reading R. R., where the switch points are curved so as to fit the stock rail, which is not bent at the switch point, but laid to an exact curve.

The custom of *half spiking* side tracks should be condemned as unsafe and very poor economy. Side tracks should receive as thorough work as the main line, though, of course, they require less of it. This point has been touched upon before.

1695. Laying Frogs in Track.—In placing a frog in the track, special care should be taken to put it in perfect line and surface with the rails with which it connects. Couple the frog to the main track rails and put them in perfect line before spiking. This is more certain to give a true line to the frog than to spike the connecting rails before coupling with the frog. If the main track is in poor line, put in track centers for lining the frog, for it is very difficult to correct defects in line after a switch is once in place. Having spiked the frog in place, put the rail opposite the frog in perfect gauge for the full length of the frog, if on a tangent, and at the point of frog, if on a curve. To have a frog in perfect gauge, try the gauge at each end of the frog, and at about six inches back of the frog point.

If the curve is very sharp and laid to a uniform gauge throughout, an ugly kink is left opposite the frog. This defect is caused by the frog rail, which is necessarily straight, and can be remedied by spiking the rail to gauge *only* at the point of frog, and allowing it to assume its natural curve for the remainder of the frog's length.

Turnout curves of long radii require *long frogs*, and the track can be spiked to proper gauge throughout its length without any perceptible kink at the frog.

Long frogs and long leads are the best where it is practicable to use them. The wear from sharp curves and short frogs, both upon rails and rolling stock, is great, and they are to be used only where limited space requires them.

1696. Switch Timbers.—Every first-class railroad has its own standards for switches, which include the necessary switch timbers. The following rule will answer well for general use:

Rule.—*To find the number of ties required for any switch lead, reduce to inches the distance from the head-block to the last long tie behind the frog, and divide this distance by the number of inches from center to center of tie; the quotient will be the number of ties required.*

EXAMPLE.—The distance from the head block to the last tie behind the frog is 77 feet. The ties are spaced 21 inches center to center. What is the number of ties required for the switch ?

SOLUTION.—77 feet = 924 inches; 924 ÷ 21 = 44, the number of ties required. Ans.

Switch ties should be 10 inches in width and at least 6 inches in thickness, though 7 inches is preferable. The head-block should be 12 inches in width and 8 inches in thickness, and 16 feet in length. When timber may be furnished in odd lengths, the following list will furnish the necessary timber for a given switch, which is a single throw, and requiring a No. 8 frog:

SWITCH TIES 21 INCHES TO CENTER.

1 head-block	8″ × 12″ × 16′ long.
8 pieces	6″ × 10″ × 9′ long.
8 pieces	6″ × 10″ × 10′ long.
8 pieces	6″ × 10″ × 11′ long.
5 pieces	6″ × 10″ × 12′ long.
5 pieces	6″ × 10″ × 13′ long.
5 pieces	6″ × 10″ × 14′ long.
3 pieces	6″ × 10″ × 15′ long.

When even lengths only can be ordered, the list must be modified, only care must be taken to have the timber long enough.

Switch ties in important yards should not be more than 9 inches apart, if they are to be kept in proper surface. It is poor economy to use inferior timber for switch ties, or a scant number of ties. Switch building is expensive work, and should be made as permanent as is practicable.

To cut switch ties the proper length apply the following rule:

Rule.—*Measure the length of the tie next the head block and the length of the last long tie behind the frog. Find the difference in inches between them. Divide this difference by the number of ties in the switch lead; the quotient will be the increase in length per tie from the head block towards the frog*

to have the ends of the ties in proper line on both sides of the track.

EXAMPLE.—The length of the tie next the head block is 8 feet 6 inches = 102 inches. The length of the last tie behind the frog is 15 feet = 180 inches. The difference between the lengths of the ties, 180 − 102 = 78 inches, which, divided by 44, the required number of ties, gives 1.8, say $1\frac{3}{4}$ inches, the average increase in length per tie.

There is nothing gained by giving to switch ties a greater projection outside the rails than ordinary track ties. They add to the labor of raising the track, are unsightly, and labor is wasted in tamping up the long ends. The switch ties should be cut to proper length, marked with chalk in consecutive numbers, and a mark for the outside flange of the main track rail placed on each tie for lining them. Any one acquainted with track work knows that the labor of cutting ties to exact length, numbering them, and marking them for proper lining is labor saved. There is then no time wasted in cutting and trying; the work can be pushed from start to finish, and the result is a perfect piece of work.

1697. Tamping Switch Ties.—Before tamping up a set of switch ties, raise the track to a uniform surface. Tamp the ties under the frog and main track rail first, raising the frog a shade higher than the rest of the switch. The head block should also be about one-quarter of an inch above the common surface, especially if a stub switch, as the continual jarring caused by wheels passing the open joint will cause the head block to settle slightly. Tamp up the middle of the ties first and then the outer ends. This will prevent any sagging of the ties at center and a corresponding rise at the ends. If possible, complete the tamping before a train passes the switch.

1698. Three-Throw Switch Timbers. — The lengths of switch timbers for a three-throw switch are found by doubling the lengths of those for a single turnout, and subtracting from each the length of the standard cross-tie.

Before placing them in the switch, draw a chalk line across the middle of each tie, and number them in the same order as in a single turnout. Then, place them under the main track rail, and make the middle mark of each switch tie coincide with the middle point of the track gauge placed on the main track above the tie.

1699. Location of Crotch Frog.—A **crotch,** or **middle,** frog is a frog placed at the point where the outer rails of both turnouts of a three-throw switch cross each other. When both turnouts are of the same degree, the crotch frog comes midway between the main track rails. Its location and angle may be determined as follows: Let the turnout curves A and B, Fig. 545, be each 9° 30′, uniting with the

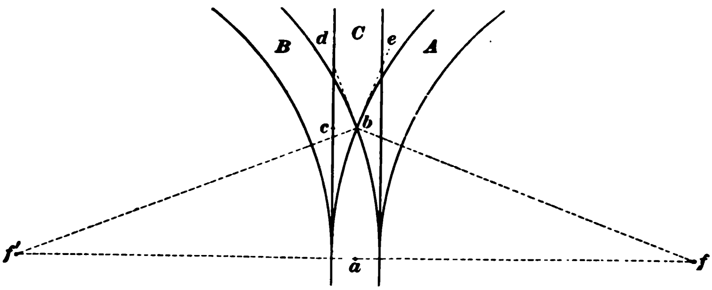


FIG. 545.

main track C by a three-throw switch. Let a be the P. C. common to both curves, and b, the location of the crotch or middle frog.

It is evident that the point of the crotch frog should be exactly midway between the gauge lines of the main track rails, and if the gauge is 4 feet $8\frac{1}{2}$ inches $= 4.71$ feet, the point of the crotch frog will be $\frac{4.71}{2} = 2.35$ feet from each rail. Now, the problem is to find the frog distance from a, the P. C., to the point c, where the tangent deflection will equal 2.35, or half the gauge. From the table of Radii and Deflections, we find the tangent deflection of a 9° 30′ curve is 8.28 feet. Applying the principle explained in Art. **1692**

and Fig. 540, and letting x represent the required frog distance, we have the following proportion:

$$8.28 : 2.35 :: 100^2 : x^2;$$

whence, $$x^2 = \frac{100^2 \times 2.35}{8.28} = 2{,}838.2 \text{ feet},$$

and $$x = 53.3 \text{ feet, nearly},$$

the required frog distance.

Now, there are two curves starting at the common point a; the outer rails intersect at b, and the angle $d\ b\ e$, formed by tangents drawn to the point of intersection, is the angle of the crotch or middle frog. The angle is equal to the sum of the angles $a\ f\ b$ and $a\ f'\ b$; that is, equal to double the central angle of either curve between the P. C. and the point of intersection b. The degree of the curve is $9° \ 30' = 570'$, and the central angle or total deflection for each foot is $\frac{570'}{100} = 5.7'$, and for the frog distance of 53.3 feet, the central angle is $53.3 \times 5.7 = 303.8' = 5° \ 03.8'$. The angle of the crotch frog is double this angle, i. e., $5° \ 03.8' \times 2 = 10° \ 07.6'$. The crotch frog should be accurately located and spiked in place before the lead rails are placed.

The one objection to the three-throw switch is the open joint at the head block, the inevitable attendant of the stub switch, but its advantages are so great that it will continue to be used, especially in yard service.

1700. Cross-Over Tracks.—A **cross-over** is a track by means of which a train passes from one track to another. The tracks united are usually parallel, as are the tracks of a double track road. Such a cross-over is shown in Fig. 546. The tracks $a\ b$ and $c\ d$ are 13 feet apart from center to center, which is the standard distance for double tracks. The cross-over consists of two turnout curves, $e\ f$ and $g\ h$. These curves are usually, though not necessarily, of the same degree. The curve terminates at the points of frog f and h, between which the track $f\ h$ is a tangent. The essential point in laying out a cross-over is to so place the

frogs that the connecting track shall be tangent to both curves. In Fig. 546, suppose the frogs are No. 9, requiring 7° 31′ turnout curves.

From Table 35, we find the required frog distance is 84.7 feet, and the switch length 25 feet. As previously noted, if there is considerable range in choice of location, the frogs can be so placed as to largely avoid the cutting of rails; but usually cross-overs are required at certain precise places, and the rails must be cut as occasion demands. Having located the point of frog at *f*, we determine the point of the next frog at *h*, as follows: A No. 9 frog is one

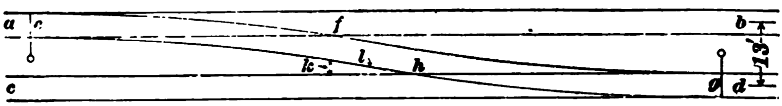


FIG. 546.

which spreads 1 inch in width to every 9 inches in length, and as the track between the frog points is straight, the distance *f h* between these points will be as many times 9 inches as is the space *k* between the tracks at the frog point *f*. The main track centers are 13 feet apart, making the space between the gauge lines of the inside rails 8 feet $3\frac{1}{2}$ inches. As it is the rail *l* of the turnout which joins the second frog at *h*, we subtract the gauge, 4 feet $8\frac{1}{2}$ inches, from 8 feet $3\frac{1}{2}$ inches, leaving 3 feet 7 inches, the distance ***k***, between the gauge line of the rail *l*, opposite the frog point *f*, and the gauge line of the nearest rail of the track ***c d***. This distance multiplied by 9 inches will give the distance from the frog point *f* to the frog point *h*: 3 feet 7 inches $= 43$ inches, $43 \times 9 = 387$ inches $= 32$ feet 3 inches. Accordingly having located the point of frog *f*, we mark a corresponding point on the nearest rail of the opposite track. From this point we measure along the rail the distance 32 feet 3 inches, locating the second frog point *h*, and again the frog distance 84.7 feet to the P. C. of the second turnout curve at *g*.

If frogs of different numbers, say 7 and 9, were to

be used, the distance between the frogs is found as follows:

As the No. 7 frog spreads 1 inch in 7 inches, and the No. 9 frog 1 inch in 9 inches, the two will together spread 2 inches in $7 + 9 = 16$ inches, or 1 inch in 8 inches. Now, if the rails to be united are 3 feet 7 inches, or 43 inches apart, as in the previous problem, the distance between the frog points will be $43 \times 8 = 344$ inches $= 28$ feet 8 inches.

In locating cross-over tracks, regard should be paid to the direction in which the bulk of the traffic moves, and the cross-over tracks should be so placed that loaded cars will be backed, not pushed, from one track to the other.

At all stations on double track roads there should be a cross-over to facilitate the exchange of cars and the making up of trains.

YARDS AND TERMINALS.

1701. This subject includes the laying out and maintenance of the extensive railway yards which are found at all terminal and division points.

A terminal to be effective must provide ample track room for all cars being stored, unloaded, or exchanged, with the tracks so arranged that terminal business may be transacted with facility and dispatch. To save time is to save money in all departments of a railroad. Much time is unavoidably consumed in transferring cars to foreign lines, making up trains, and shifting cars to freight depots or side tracks for unloading; but a badly arranged yard involves *waste of time* and *increased forces of men and engines.* Hence, the laying out of yards and terminals should be placed in the hands of men of judgment and large experience. Furthermore, a railroad company can well afford to incur large expenditure in first cost if they thereby avoid the continual extra expense due to badly arranged yards and terminals.

A well-arranged terminal is shown in Fig. 547, in which practically all the requirements for local and through traffic

and for traffic exchange, both by rail and water, are fully met.

The railroad has a double track, *a a'* and *b b'*. The passenger station *A* is placed where two important streets intersect, and should be as near the center of population and business as is practicable. This station combines two buildings, the one *c* in front, containing the passenger, baggage, and express rooms on the first floor and the general offices of the company on the upper floors. The rear building *d* is a train shed, and contains six tracks, with platforms between. These platforms should be from 8 to 10 feet in width, so that passengers need not crowd each other while taking the cars. In many of the best stations, these platforms are of concrete, finished smooth with Portland cement. This makes an excellent walk, is fireproof and enduring. The roof should be of iron, and the entire station made fireproof, if practicable.

Empty passenger coaches are stored on the tracks *e*, convenient to the station. The freight station and offices are shown at *B*. This station is in four parts. The first part *f*, in front, contains the freight offices, and is usually two or three stories in height. The parts *g* and *h* are freight rooms for receiving and discharging freight. The part *k* is a train shed, containing six tracks, allowing three rows or banks of cars for each freight room. The cars are backed into the train shed with the car doors on each track on line with those on the adjoining tracks. Bridges of either planks or sheet iron extend from car door to car door, so that two or three rows of cars may be loaded at the same time. By this means a way freight train for a long line with numerous stations may be loaded with dispatch and without confusion.

The freight rooms have no outside platforms. Drays loaded with outgoing freight back up to the doors of the freight room; the freight is discharged directly into the freight room, and often is carried by trucks directly from the drays to the car. This saves the delay and expense of rehandling, which would result from discharging from

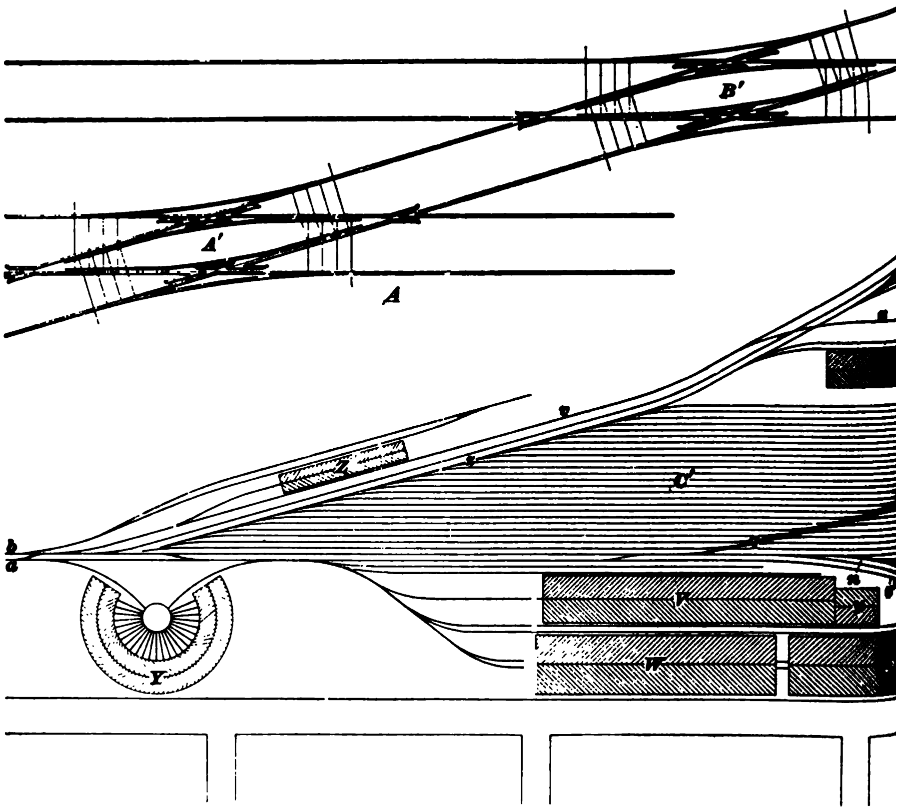
drays to a platform. Trains of local freight are stored on the tracks *l* while awaiting their turn for unloading, and cars laden with outgoing freight may be stored on the tracks *m* until a train is made up.

It will be observed that the main tracks *a a'* and *b b'* are comparatively free from switches, excepting at the passenger train yard and station. All tracks entering the passenger station *A* connect with the outbound track *b b'*. All the tracks connecting with the freight station *B* are thrown from the main stem track *n*, which connects with the outbound main track *b b'*. The streets *o* and *p*, adjoining the freight station, are extended to accommodate drays or other vehicles while unloading freight in car lots from the adjoining sidings.

The track *q r* is sometimes called a ladder track. It runs diagonally across the yard, intersecting all tracks and connecting with each by means of slip switches, shown in detail at *A'* and *B'*. This track extends to the steamship wharves *C* and *D*. Two tracks run alongside each pier, the tracks being depressed so as to bring the car floors nearly on a level with the deck of the pier. The passenger room and steamship offices are at *E*. Additional side tracks for local freight in car lots are shown at *s* and *t*. Additional railroad wharves are shown at *F*, *G*, and *H*. Wharves should be covered with strong sheds, and when the pier foundation is of stone or creosoted piles, it is economy to build the shed of iron. Grain elevators are shown at *I* and *K*. The tracks, five in number, run between the elevators, giving abundant dockage for ships on either side.

The wharves *L*, *M*, *N*, *O*, *P*, and *Q* are for coal traffic. The piers support coal pockets, which have sufficient elevation to cause the coal to run by gravity into the holds of vessels lying alongside. The track *v*, connecting with the main track *b b'*, has an ascending grade not to exceed 2 per cent., which gives sufficient elevation to the spur tracks running on to the coal wharves.

Track *x*, connecting with the elevated track *v*, leads to a coal chute *R*. The buildings shown at *S*, *T*, and *U* are


B'
A'
A
b
a
v
Z
C'
V
W
Y

An observing, alert man will soon become expert in detecting the different movements of the car as it swings to either side of the track, and should determine the cause by walking over the track immediately after riding over it, and remedy the defects in the track.

1703. Avoid Attaching Hand or Push Cars to Trains.—Foremen should never attach a hand or push car to a train to avoid the labor of pumping or pushing the car to its destination. Many serious accidents have resulted from such action. The sudden slackening or stopping of a train is likely to throw the hand or push car under the train in spite of every effort to prevent it, and serious injury, if not death, is the sure result.

1704. Always Carry a Track Jack.—Foremen should never be out on their sections without a track jack. Keep it on the hand car when not in use, so it will always be available. In no way is time oftener wasted than in attempting to raise a rail with a makeshift lever when the track jack has been left behind at the section house. Frequently, the spikes are drawn from the ties and the track marred both in gauge and surface by it.

The track jack is one of the best and most economical tools in use upon a railroad, and every section should possess one and make the utmost use of it.

1705. The Track Level.—Always carry a track level when going out on the section to pick up or surface track. It is useless to attempt to surface track without a spirit level, though low spots in a track which has once been put in good surface may be put in proper surface by sighting.

1706. Rails of Different Heights.—Where rails of different heights meet at a joint, they should be connected by a *step splice*, and an iron shim should be placed under the low rail, to bring the tops of both rails to the same level. The shim should be slotted at the sides, and spikes driven through the slots, to hold the shim in place.

1707. Extra Men.—When a section foreman is about to largely increase his force for temporary work, he should take time to carefully plan his work and the disposition of his men. Work well organized is half done.

1708. Getting Acquainted with the Section.—Every section foreman should, immediately upon taking charge of his section, thoroughly acquaint himself with everything connected with it and his work. He should know the length of his section, the location and degree of each curve, the number and location of each bridge, trestle, cattle guard, crossing, and culvert, the weight, brand, and age of all steel and its location, the number of panels of snow fence, the height of bridges from the ground, the location of whistling posts, the numbers of all frogs, and any information which can assist a foreman in making out correct and prompt reports to the roadmaster.

1709. Drilling Rails.—When it is necessary to cut rails in putting in switches, or in repairing track, the rails should be full drilled and bolted at every joint. A joint but half bolted is sure to sag in a short space of time.

1710. Lining Disconnected Track.—When lining disconnected track that has been washed out, always commence at the connected end, else it will be practically impossible to get the track in line.

1711. Cutting Steel.—Section foremen should carefully instruct their men how to cut rails. The cut of the chisel should be a continuous line extending entirely around and square across the rail. Iron rails require deeper cutting than steel rails. To break off a rail at the cut, lift up the end nearest the cut and let it fall across a piece of rail laid on a tie. If but a short piece of the rail is to be broken off, a sharp blow from a sledge is the surest way to break it. Hard steel, if cut too deep, is liable to become softened by the battering of the chisel, and in breaking leave a rough, unshapely end on the rail. A spike maul should not be used to strike the head of either chisel or punch, as it is

sure to destroy the face of the maul and split pieces out of the head of steel tools. A sledge of suitable weight, made for the purpose of striking hard steel tools, should be used instead.

Cold chisels when first dressed by the blacksmith are not always well tempered at the point, and in using a newly sharpened chisel, light and careful blows should be given first. If the tool is well tempered, the edge will hold, but if poorly tempered, the edge will chip slightly. The chisel should then be ground to a true edge, which generally toughens it, and it will cut a number of rails before it is necessary to send it to the shop again.

1712. Distance at Which to Place Danger Signals.—Danger signals should be placed at distances not less than 3,500 feet in each direction from the point where the track is impassable for trains. The distance can be measured by counting 117 rails of 30 feet each from the point of danger, or, where the telegraph poles are 150 feet apart, place the signals 23 poles distant from the point of danger. If the point of danger is at the foot of a heavy grade, where it is difficult to stop a train, the distance of the danger signal should be increased to even double the ordinary distance, or the telegraph operator at the nearest station informed of the danger, so that he may notify the train dispatcher, who will at once warn all trains within danger, and they can be held until the track is safe for their passage. Where there is a sufficient force of men to make repairs, the flagman should remain with the danger signal until the track is repaired or the train stopped. In foggy or stormy weather, the *flagman must always remain out with the signals until all danger is passed.* As soon as the track is safe for the passage of trains, flags, torpedoes, or other signals should be removed at once.

Foremen should always carry flags and torpedoes on their hand cars, and fully instruct their men in the use of them. They should be fully posted on the time of all

regular trains, and should be on the watch for signals carried by regular trains.

1713. Signals.—In setting a signal requiring a train to run slowly, called a *slow flag*, place the flag on the *engineer's side of the track*, the right hand side, slightly leaning, so that most of it can be seen, and just far enough from the rail to clear the engine and cars.

A slow signal is set out *one-half mile*, about 17 telegraph poles, distant.

A red flag or light, which is a *stop signal*, should be placed in the center of the track. Two torpedoes should be placed on the same rail, about 60 feet apart, between the stop signal and the approaching train.

1714. Location of Whistling Posts and Signs.—Station whistling posts should be placed one-half mile outside the switch, not the depot, and on the engineer's side (the right side) of the track to one approaching the station. Station mile boards should be placed one mile *outside the switches*. If the post were placed but one mile from the station, it would, in large yards, often fall inside the switches. The object of these signs is to warn trainmen of the near approach of a station in order that they may have the train under control before reaching the station.

Whistling posts for highways should be placed one-quarter of a mile from the crossing, and on the engineer's side of the track. Whistling posts or other signs should never be placed in a cut where they will not be readily seen. If on a descending grade, place the sign outside the cut, increasing the distance; if on an ascending grade, decrease the distance. This rule also applies to sharp curves. All signs carrying a cross-board should have the board placed at right angles to the track. Highway crossing signs should be placed parallel to the rails, so that they may be distinctly read by persons approaching the track. All posts carrying signs should be vertical, and securely set in the ground, and so placed as not to come in contact with either trains or vehicles.

1715. Obstructing the Track.—The track should never be so used as to obstruct a regular train, nor should any work be undertaken which can not be finished, and the track made safe, fully 15 minutes before the train is due. In case of a delayed passenger train, the track must be kept constantly safe and clear, and if repairs must be made, a responsible man, preferably the foreman himself, should remain out with signals until the track is safe and clear.

Some foremen have a habit of leaving the hand or push car on the track while repairs are being made. This is a dangerous practice, and contrary to the rules of any well-managed railroad. The hand car should not only be kept clear of the track when not in use, but should not be left in the way of road or farm crossings.

1716. Hand-Car and Tool Houses.—Hand car and tool houses should be placed outside the switches at yards and stations, so that trains standing on the side track will not deter section men with their hand car from going to work. Tool houses must be far enough from the track to prevent obstructing the view of passing tralns.

1717. Throwing Switches.—Foremen should not throw switches for trivial reasons. An empty hand car or push car should always be carried from one track to another, and, if carrying a light load, it can be handled without throwing a switch. Most foremen carry a switch key, but it should be used with proper discretion and *never in the absence of the foreman.* The person tending to the switch *should always remain by it until it is set for the main track and locked.* Any foreman who makes a practice of throwing switches where it is unnecessary should be discharged at once.

1718. Care of Tools.—The section foreman is responsible to the railway company for all tools and other supplies issued to him. The systematic use and care of tools will greatly increase their efficiency and prolong their

service, and it is evident that the foreman can not better serve his company than by instructing his men in the proper handling and care of tools.

Hand cars and push cars should be oiled regularly, the axle and other boxes kept tight, and the cars kept always ready for service. Hand cars should not be used to carry steel except in emergencies, and then only a light load should be taken, the rails being placed on both sides of the car so as to balance. Both rails and ties should be transported on the push car.

Shovels figure largely in the tool account chargeable to track repairs. On most sections this account is unnecessarily large, owing to the many improper uses to which the shovel is put. A shovel should never be used to hold up the end of a tie for spiking, nor driven into a tie in place of a pick to pull the tie into its trench in the track. As soon as the edge begins to turn, it should be straightened, and, if necessary, trimmed with a cold chisel. Proper care will often double the life of a shovel.

Claw bars should never be used to pry up the track, and, above all, in frosty weather, as the claws are then easily broken, and are always difficult to repair.

1719. Care of Material.—A sure test of a good foreman is his care for all material placed in his charge. Whenever track repairs of any kind are made, all loose material of every kind should be collected, and, with the exception of rails, should be carried to the section house, where it may be sorted. Much old material, such as splice bolts and spikes, may, with a little straightening, be made to serve a second time and be as serviceable as new material. All old iron should be piled in places convenient to the track, whence it may be shipped at the direction of the roadmaster.

1720. Care of Station Grounds.—It is particularly to the section foreman's interest to keep the station grounds in perfect order. By a little thought and planning, he can find time to grade the approaches to the station, plant a few

shade trees, and do some sodding where it will tell. This work must not be done at the expense of regular track work, but a spare hour is often available, and the results, if the time has been wisely expended, amply pay for the outlay. Neat station grounds encourage travel, and are sure to win the approbation of superior officers.

1721. Work-Train Service.—The foreman in charge of a work train should make it his business to keep his men at work whenever the train is delayed. There is always plenty of work to do along the track at any point, and by proper forethought and planning, these unavoidable delays may be turned to full account.

Every work train should be in charge of a thorough trackman, who should, in addition, be thoroughly competent to run a train.

Work-train conductors and foremen in charge of gravel pits or of steam-shovel outfits should receive their orders from and be responsible to the roadmaster of the division upon which they are working. They should send in a daily report to the roadmaster, and every evening after quitting send in to the dispatcher *a lay-up report*, stating where they will work the following day. Work trains should always lay up at a telegraph station.

Conductors in charge of work trains should see that all axle boxes are properly packed and oiled, and any accidents to cars or any part of the outfit should be promptly reported to the roadmaster.

1722. Track Inspection.—There should be a well-organized system of track inspection on every railroad. The amount of inspection should be in proportion to the excellence of the track and the amount of traffic. Whatever the amount of traffic, the entire section should be inspected each day. In ordinary weather this work may be entrusted to a careful section hand, but in stormy weather the *section foreman* should give his entire section a careful inspection. It is best that the track inspection, especially at the more dangerous points, should be made before the passage of express

trains. On double-track roads where the traffic is heavy, track inspection is performed by regular track walkers. They should always carry a track wrench, to tighten loose bolts, and a flag and torpedoes for signals. During the winter months, when the ground is frozen solid, the frost, which hinders many kinds of general track work, is constantly heaving the track out of line and surface, and greatly increasing the danger of accident. A rule requiring the section foreman to see his entire section daily should be strictly enforced. During extremely cold weather the track requires constant watching. During heavy storms, it is a good plan to go by train against the storm, to the end of the section, and inspect the track while returning on foot. Two or three inspections in a day are none too many for severe, stormy weather.

1723. Methods of Work.—Every foreman should be on the alert to learn new and approved methods of work. By careful thought he may devise time and labor-saving methods himself. Work slowly done is not necessarily well done. In fact, expedition is an adjunct to excellence, as no man can do work rapidly without giving it his full attention, and any work, however simple, that has heart put into it, will show it by superior excellence.

1724. Discipline.—A foreman to succeed must be superior to his men both in knowledge and in force of will. Abusive and profane language will soon demoralize men, robbing them of all respect for their foreman and for themselves. Patience in teaching men their duties and habitual fair treatment will make an enviable reputation for any foreman. He will always receive prompt and efficient service from his men, can always count on a full gang, and can readily increase his force for an emergency. Railroad companies always prefer to fill their important offices with men who have been tried and promoted in their own service. The young foreman may be sure that competence and faithfulness will not go unrecognized or unrewarded. He should take advantage of every opportunity to increase his know-

ledge of his craft, and do all in his power to make it rank as a profession.

1725. Section Records.—Every section foreman should keep a record of everything connected with the track under his charge. This record should be neatly and clearly arranged, and should contain all information which may be used as a basis for estimates, for the location of structures, or for the distribution of material.

The following will suggest suitable forms for such a record:

SECTION NO. 8.

Length of section........6 miles 1,500 feet
Length of east side track........1,200 feet
Length of station side track.....1,600 feet
Length of west side track........1,400 feet.

Bridge Number.	Number of Bents.	Length of Span.	Distance from Station.
60	4	48 feet	3 miles
61	7	84 feet	$3\frac{3}{4}$ miles
62	Iron	90 feet	$4\frac{1}{4}$ miles
Culvert Number.	**Box Culvert.**	**Iron Pipe.**	**Distance from Station.**
176	1	....	$1\frac{1}{4}$ miles
177	....	1	2 miles
178	1	....	$5\frac{1}{2}$ miles
Cuts, Length in feet.	**Height above Rail.**	**Material.**	**Distance from Station.**
One, 425	6 feet	Clay	$2\frac{1}{2}$ miles
One, 650	4 feet	Gravel	$3\frac{1}{2}$ miles
One, 500	8 feet	Rock	5 miles
Steel Rails, Amount.	**When Laid.**	**Brand.**	**Extends from Station.**
3 mi. 1,000 ft.	1884	E. Thompson	North
3 mi. 500 ft.	1889	L. I. & S. Co.	To end of Sec.

1726. Average Day's Work for One Man.—The following is a list of the various kind of labor connected with track work, and gives the amount of each which a good man can perform in one day. This will serve to show the relation existing between the labor of one man and a gang of men at any of the different kinds of work specified:

One man can

Place on a grade one-eighth of a mile of ties.

Spike one-tenth of a mile of track laid on soft ties.

Spike one-fourteenth of a mile of track laid on hard ties.

Splice and bolt one-sixth of a mile of track.

Clean with a shovel one-eighth of a mile of average weeds.

Unload 10 cars of gravel.

Unload 8 cars of dirt.

Load upon cars, 18 to 24 cubic yards of gravel.

Load upon cars, 20 to 25 cubic yards of dirt.

Load coal into buckets for engines, 15 to 20 tons.

Unload coal into sheds, 25 to 30 tons.

Put into dirt ballast track, 20 new ties.

Put into gravel ballast track, 15 new ties.

Put into stone ballast track, 8 to 10 new ties.

Do labor equal to ballasting 60 feet of gravel ballasted track.

Do labor equal to ballasting 35 feet of stone ballasted track.

Chop 2 cords of 4 ft. wood.

Make 15 to 25 hard wood ties.

Make 35 to 40 soft wood ties.

Sixty men can lay one mile of track in a day.

1727. Tables of Material Required for One Mile of Track:

TABLE 36.

TONS OF RAILS REQUIRED PER MILE OF TRACK.

Weight per Yard.	Tons (2,240 Lb.) per Mile.		Weight per Yard.	Tons (2,240 Lb.) per Mile.	
Pounds.	Tons.	Pounds.	Pounds.	Tons.	Pounds.
8	12	1,280	56	88	....
12	18	1,920	57	89	1,280
16	25	320	60	94	640
25	39	640	62	97	960
28	44	....	64	100	1,280
30	47	320	65	102	320
35	55	....	68	106	1,920
40	62	1,920	70	110	....
45	70	1,600	72	113	320
48	75	960	76	119	960
50	78	1,280	80	125	1,600
52	81	1,600			

To find the number of **gross tons** of rails required for one mile of track:

Rule.—*Divide the weight per yard by 7 and multiply the quotient by 11.*

Example.—For 70 lb. rail. $70 \div 7 = 10$; $10 \times 11 = 110$ tons.

TABLE 37.

NUMBER OF CROSS-TIES PER MILE.

Distance, Center to Center.	Number of Ties.
$1\frac{1}{2}$ feet	3,520
$1\frac{3}{4}$ feet	3,017
2 feet	2,640
$2\frac{1}{4}$ feet	2,348
$2\frac{1}{2}$ feet	2,113
$2\frac{3}{4}$ feet	1,921
3 feet	1,761

TABLE 38.

NUMBER OF RAILS, SPLICES, AND BOLTS PER MILE OF TRACK.

Length of Rail.	No. of Rails per Mile.	No. of Splices.	No. of Bolts, 4 to Each Joint.	No. of Bolts, 6 to Each Joint.
18 feet	584	1,168	2,336	3,504
20 feet	528	1,056	2,112	3,168
21 feet	503	1,006	2,012	3,018
22 feet	480	960	1,920	2,880
24 feet	440	880	1,760	2,640
25 feet	422	844	1,688	2,532
26 feet	406	812	1,624	2,436
27 feet	391	782	1,564	2,346
28 feet	377	754	1,508	2,262
30 feet	352	704	1,408	2,112

TABLE 39.

RAILROAD SPIKES PER MILE OF TRACK.

Size Measured Under Head.	Average Number per Keg of 200 lb.	Ties 2 Ft. Between Centers, 4 Spikes to a Tie.		Rails Used, Pounds per Yard.
		Pounds.	Kegs.	
$5\frac{1}{2} \times \frac{9}{16}$	375	5,870	$29\frac{1}{3}$	45 to 70
$5 \times \frac{9}{16}$	400	5,170	26	40 to 56
$5 \times \frac{1}{2}$	450	4,660	$23\frac{1}{3}$	35 to 40
$4\frac{1}{2} \times \frac{1}{2}$	530	3,960	20	28 to 35
$4 \times \frac{1}{2}$	600	3,520	$17\frac{2}{3}$	24 to 35
$4\frac{1}{2} \times \frac{7}{16}$	680	3,110	$15\frac{1}{2}$	20 to 30
$4 \times \frac{7}{16}$	720	2,910	$14\frac{3}{4}$	
$3\frac{1}{2} \times \frac{7}{16}$	900	2,350	11	16 to 25
$4 \times \frac{3}{8}$	1,000	2,090	$10\frac{1}{2}$	
$3\frac{1}{2} \times \frac{3}{8}$	1,190	1,780	9	16 to 20
$3 \times \frac{3}{8}$	1,240	1,710	$8\frac{1}{2}$	
$2\frac{1}{2} \times \frac{3}{8}$	1,342	1,575	$7\frac{7}{8}$	12 to 16

TABLE 40.

NUMBER OF TRACK BOLTS IN A KEG OF 200 LB.

Rails Used.	Bolts.	Size Nuts.	Bolts in Keg.	Kegs per Mile.
40 to 70	$\frac{3}{4} \times 4\frac{1}{2}$	$1\frac{1}{2}$ sq.	195	7.3
40 to 70	$\frac{3}{4} \times 4$	$1\frac{1}{2}$ sq.	200	7.1
40 to 70	$\frac{3}{4} \times 3\frac{3}{4}$	$1\frac{1}{2}$ sq.	208	7.0
40 to 70	$\frac{3}{4} \times 3\frac{1}{2}$	$1\frac{1}{2}$ sq.	216	6.6
25 to 40	$\frac{5}{8} \times 4$	$1\frac{1}{4}$ sq.	305	4.7
25 to 40	$\frac{5}{8} \times 3\frac{1}{2}$	$1\frac{1}{4}$ sq.	329	4.3
25 to 40	$\frac{1}{2} \times 3\frac{1}{2}$	1 sq.	576	2.6
18 to 20	$\frac{1}{2} \times 2\frac{1}{2}$	1 sq.	654	3.3
40 to 70	$\frac{7}{8} \times 3\frac{1}{2}$	$1\frac{3}{4}$ hex.	170	8.3
40 to 70	$\frac{3}{4} \times 3\frac{3}{4}$	$1\frac{3}{8}$ hex.	237	6.0
40 to 70	$\frac{3}{4} \times 3\frac{1}{2}$	$1\frac{1}{2}$ hex.	228	6.3
40 to 70	$\frac{3}{4} \times 4$	$1\frac{3}{8}$ hex.	220	6.5
25 to 40	$\frac{5}{8} \times 3\frac{1}{2}$	1 hex.	415	3.4

RAILROAD STRUCTURES.

WOODEN TRESTLES.

1728. Extent of Trestling.—The amount of wooden trestling in use on American roads is very large, and covers a wide range in both material and design. As the period of construction is always a severe test of the financial strength of a railroad company, it has been the almost universal policy in this country to use temporary structures of moderate cost, wherever possible, and to defer the erection of permanent structures until traffic is on a paying basis and finances are easy. Hence it follows that of the 2,500 miles of trestle now in use on American roads, fully one-quarter will be replaced by embankment. Of the remaining 1,900 miles, at least 800 miles will be maintained in wood. It is, therefore, a matter of great importance that these structures, whether temporary or permanent, should be well planned and constructed in order that they may best meet the requirements of safety and economy.

1729. Average Life of a Wooden Trestle.—The average life of a wooden trestle is taken at 8 years, and the question of renewal will depend upon the comparative cost of an embankment with the requisite amount of masonry for watercourses, or for the rebuilding of the wooden structure at intervals of 8 years. Trestles which are to be replaced by embankments may properly differ considerably in design from those which are to be periodically renewed. Temporary trestles should possess the qualities of simplicity and strength alone, while those which are to be

TABLE 41.

Showing Approximate Relative Cost of Embankment and Trestle in Sections of 100 feet, excluding Rails, Ties, and Ballast on Former, and Rails, Guard-rails, and Ties on Latter.

Height from Surface of Ground to Grade (sub-grade) in Feet.	Embankment per Cubic Yard in Cents. Roadbed 14 feet wide, Slope 1½ to 1.				Trestle. Timber Erected (including Iron) per M., B. M.					
					Pile Trestle—Piling, 35c. per lin. ft. in place; average penetration, 10 ft.			Framed Trestles.		
	16	**18**	**20**	**22**	**$30**	**$35**	**$40**	**$30**	**$35**	**$40**
5	$64	$72	$80	$88	$376	$407	$439	$283	$330	$378
10	113	127	141	155	441	476	512	385	449	514
15	325	366	406	447	508	544	580	464	541	618
20	521	587	652	718	576	613	651	541	631	721
25	764	859	955	1,050	748	803	858	796	928	1,060
30	1,049	1,180	1,312	1,443	816	872	928	872	1,017	1,163
35	1,380	1,552	1,725	1,897	990	1,065	1,140	1,058	1,234	1,410
40	1,754	1,974	2,193	2,412	1,057	1,132	1,218	1,133	1,322	1,510
45	2,174	2,446	2,717	2,989	......	......	......	1,202	1,404	1,606

maintained in wood should be so designed that they may be renewed without any interruption of traffic. In either case, the use of any other than the best available material is to be condemned as poor economy. The cost of the construction of a trestle is a considerable percentage of its total cost, and is but slightly affected by the character of the materials composing it, and, hence, the small saving effected by the use of cheaper materials is neutralized by the shortened life of the structure and its general lack of excellence

A *good* wooden structure is preferable to a *cheap* iron one, though the impression commonly prevails that an iron structure must necessarily be strong and efficient. Many new lines traverse sections where timber is abundant and cheap, bringing the cost of wooden structures within safe reach of the railroad company, whereas costly structures of iron or heavy fills might have wrecked the company and the enterprise.

1730. Comparative Cost of Trestles and Embankments.—The height at which it becomes more economical to substitute trestling for embankment varies widely, depending upon the locality, the cost of timber, labor, and the character of material available for making the fill. There are, of course, many situations, such as deep swamps or waterways, where an embankment is out of the question. It then becomes a choice between wooden and iron structures.

The cost of an embankment increases in a vastly greater ratio than its height, as will be seen from Table 41. The cost of trestling, on the other hand, does not increase nearly as rapidly as its height, especially for heights under 50 feet. The cost of pile and framed trestles for heights from 5 to 45 feet, inclusive, is given in Table 42.

1731. Mathematical Formulas of Slight Use in Trestle Designing.—Few engineers employ mathematical formulas in designing trestles. The strength and properties of timber vary with each separate piece, and in proportioning

the parts of a trestle it is far safer to rely upon one's own judgment, if supported by large experience, or to follow the approved examples of other men, than to rely upon any set of mathematical formulas. American railroads show a wide range in trestle design, each important road having a set of standard designs which may differ more or less from those employed on other lines. The designs given in this paper are copies of some of the best standards in use on American roads, and cover a range wide enough to meet the requirements of all ordinary situations.

TABLE 42.

Cost of Pile and Framed Trestles, complete, including Floor Systems for Different Heights in Sections of 100 feet.

Height in Feet.	Pile.			Framed.		
	$30	**$35**	**$40**	**$30**	**$35**	**$40**
5	$546	$605	$665	$453	$528	$604
10	611	674	738	555	647	740
15	678	742	806	634	739	844
20	746	811	877	711	829	947
25	918	1,001	1,084	966	1,126	1,286
30	986	1,070	1,154	1,042	1,215	1,389
35	1,160	1,263	1,366	1,228	1,432	1,636
40	1,227	1,332	1,444	1,303	1,520	1,736
45	....	....	....	1,372	1,602	1,832

1732. Classes of Trestles.—Wooden trestles are divided into two general classes, viz., **pile trestles,** in which the bents consist of piles united by a cap, and **framed trestles,** in which the bents consist of squared timbers framed together. Pile trestles are rarely used for heights exceeding 30 feet. Framed trestles may be of almost any

height, though special designs are required for those exceeding a height of 30 feet.

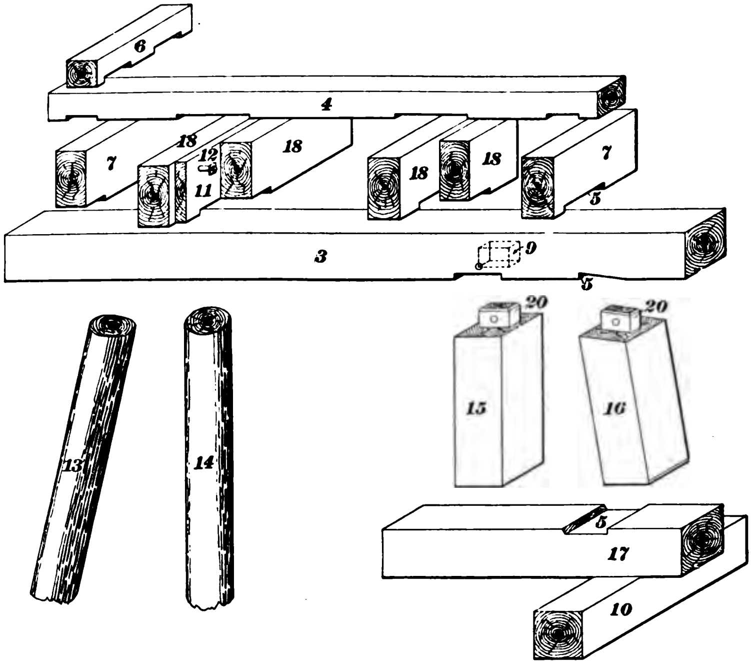


FIG. 548.

1733. Technical Terms and Names.—In order that the student may understand the various parts composing a trestle, the following technical terms and names are

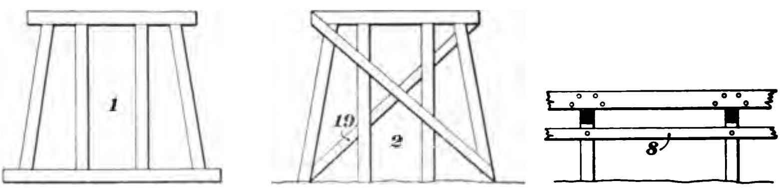


FIG. 549.

given, the number accompanying each term corresponding to the parts given in Figs. 548 and 549:

Bent, Framed, 1.
Bent, Pile, 2.
Cap, 3.
Cross-tie, 4.
Dapping, 5.
Gaining, see Dapping, 5.
Guard-rail, 6.
Jack-stringer, 7.
Longitudinal Brace, 8.
Mortise, 9.
Mud-sill, 10.
Notching, Gaining, Dapping, 5.
Packing-block, 11.
Packing-bolts, 12.
Piles, Batter, Inclined, Brace, 13.
Vertical, Plumb, Upright, 14.
Posts, Vertical, Plumb, Upright, 15.
Batter, Inclined, 16.
Sill, 17.
Stringer, 18.
Sway-brace, 19.
Tenon, 20.
Waling-strip, see Longitudinal Brace, 8.

1734. Pile Bents.—As the subject of **pile driving** was fully discussed in the section on Railroad Construction, no reference will be made in this section to the *theory* of pile driving. Where the line traverses low, marshy ground, either constantly overflowed or subject to occasional overflow, and where the height of the rails above the surface of the ground does not exceed 30 feet, a pile bent is generally adopted. When pile bents are used for greater heights than 30 feet, only the tops of the piles penetrate the ground, and though they may reach a substantial bottom, the bent is essentially weak, owing to the small diameter of the pile and the small proportion of heart timber at the top of the tree. It is the *heart timber* alone which can long resist decay, and at the surface of the ground, where the timber is alternately wet and dry, decay sets in as soon as the structure is erected, and in a few years, at best, the piles must be renewed, though the remainder of the trestle may be in a comparatively sound condition.

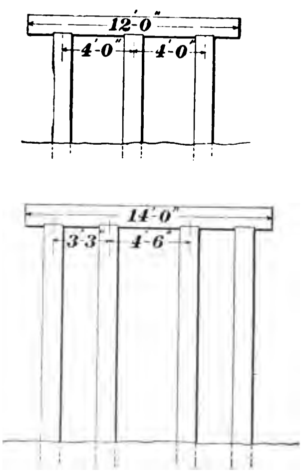
Piles should be cut from live, straight, thrifty trees, free from dead or loose knots, wind shakes, and all descriptions of decay, and be stripped of bark. They should have a butt diameter of from 12 to 15 inches, and a top diameter of from 7 to 10 inches inside the bark. *Squared* piles are used in a

limited way, and when so used they should measure 12 inches square at the butt, and not show more than 2 inches of sap wood on the corners. It is the custom on some lines to paint the pile for a short distance above and below the ground line with hot tar, thus tending to retard decay.

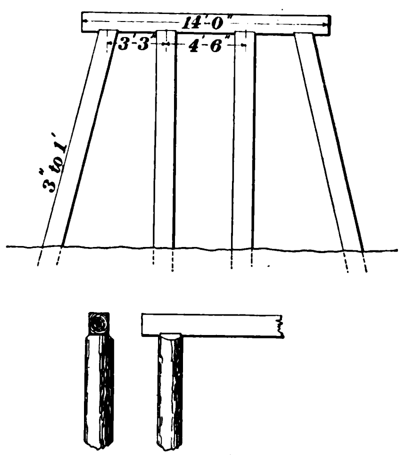
Timber suitable for piles may be found in most sections of the United States. The different varieties of timber commonly used for piling are named in the following list in the order of their excellence:

Red Cedar,	White Pine,	White Oak,
Black Cypress,	Redwood,	Post Oak,
Pitch Pine,	Elm,	Tamarack,
Yellow Pine (long-leaf),	Spruce,	Hemlock.

The arrangement of the piling forming the bent varies considerably with different constructors in the matter of



FIGS. 550 and 551.



FIGS. 552 and 553.

spacing the piles, though the general arrangement is the same.

For a height of bent not exceeding 5 feet, and where the

road is to carry only a moderate traffic, a three-pile bent is generally adopted, one pile being placed directly upon the center line and the others spaced from 3 feet 6 inches to 5 feet out, the piles being driven vertically. (Fig. 550.) For trunk lines, however, whatever the height, all bents should contain four piles.

For heights of from 5 to 15 feet, each bent should contain four piles driven vertically. The inner piles may be spaced from 4 to 5 feet and the outer ones about 11 feet from center to center. (Fig. 551.) Pile bents of this height will not require sway bracing, provided the penetration amounts to 6 or 8 feet in firm earth. For heights exceeding 15 feet, it is well to batter the outside piles, as shown in Fig. 552. By this means the width of the base is considerably increased, giving in appearance, as well as in fact, greater stability to the structure. Piles are battered from 2 to 4 inches to the foot, 3 inches being commonly adopted.

On Western roads, vertical pile bents of heights of 20 feet and over are frequently seen, but they give the impression of a lack of stability, which the battered piles at once remove. Where the diameter of the pile at the cut-off point exceeds the width of the cap, the part of the pile which projects should be adzed off at an angle of 45°. (Fig. 553.)

1735. Splicing Piles.—When the material into which the piles are driven is soft ground, extending to a great depth, it may be necessary to *splice* the piles in order to reach a firm foundation. In **splicing,** the piles are placed end to end, and united either by dowels, bands, or scarfings. Three different forms of splices are shown in Figs. 554, 555, and 556. Those shown in Figs. 554 and 555 are commonly adopted. The first pile is driven until its top is within easy reach from the surface of the ground. It is then cut off and trimmed up for splicing, and the second pile placed upon and fastened to it. When the ground is in a partially fluid state, the pile already driven will have but little stiffness, so that if either of the splices shown in

Figs. 554 and 555 is used, the piles are liable to cant in driving and the splice to give way. In such cases it is better to strengthen the splice with scarfings, say 3 inches by 3 inches by 8 or 10 feet in length, spiked to the piles as shown in Fig. 556. This splice was used in the false work for the erection of the Poughkeepsie bridge, and proved very efficient. When the band splice (Fig. 555) is used, some device must be used to keep the band in place, else, after a few blows of the hammer, it will be found wholly on one pile or the other. Railroad spikes driven above and below the band, as shown in Fig. 555, will prevent this movement.

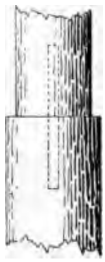


FIG. 554.

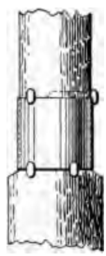


FIG. 555.

1736. Determining the Length of Piles Required.—If the bridge is to be a long one, requiring a large number of piles, it is important that the approximate lengths of the piles required and the number of each should be known before ordering the material. The following method, adopted by the Northern Pacific Railroad Company for their bridge over the St. Louis river, at Duluth, proved very satisfactory. Test piles were driven every 300 feet along the center line, and where any considerable variation in penetration was noticed, an intermediate pile was driven. The piles were driven from a scow, the space between the piles being regulated by a rope attached to the last pile driven. After the piles were all driven, their exact location was determined by triangulation. A careful record was kept of the driving of each test pile, the notes being kept in the following form:

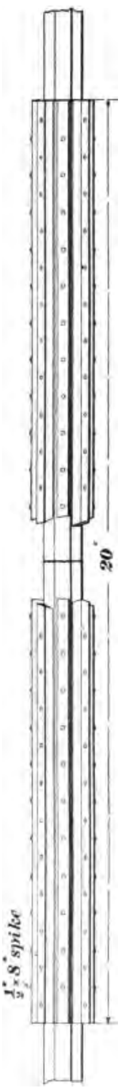


FIG. 556.

Station.	No. of Pile.	Length.	Diameter of Top.	Diameter of Butt.	Depth of Water.	Distance Driven.	Elev. Top of Pile.	Elev. Point of Pile.	No. of Blows.	Fall of Hammer.	Wt. of Hammer, lb.	Penetration for Each Ten Consecutive Blows. 40	50	60	70	80	90	100	110	120	130	140	150
80+23.7	16	52′	8½″	15½″	9.7′	39.3′	84.8′	32.8′	120	20′	2,256	. .	. .	13″	14″	16″	17″	15″	12″	12″	. .	. .	. .

NORTHERN PACIFIC RAILROAD COMPANY.

BRIDGE NO. 160. PILE-DRIVING RECORD.

Date and Station.	No. of Bent.	No. of Pile.	Kind of Timber.	Length of Pile.	Diameter of Butt.	Diameter of Top.	Length Below Cut-Off.	Length of Cut-Off.	Elevation of Ground.	Elev. of Point of Pile.	Distance Driven.	Fall.	No. of Blows.	Penetration for Given Number of Blows.					
				Ft.	In.	In.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.							
Dec. 27 114+30	42	1	Wh. Pine	40	17	14	31.4	8.6	76.2	66.4	9.8	20	85	20	10″	10″	5″	4″	1″
															40	60	70	80	85
Jan. 10 112+65	53	3	Wh. Pine	42	15	13	36.0	6.0	74.8	61.8	13.0	18	50		. .	. .	11″	11″	9″
															. .	20	30	40	50

SUMMARY OF WORK ON ONE DRIVER.

Dates.	Number of Days.	Number of Piles Driven.	Lineal Feet of Piles Driven.	Number of Piles Driven Daily.	Lineal Feet of Piles Driven Daily.	Contractor's Cost of Driving.	Average Cost of Driving per Lineal Foot.
1885.							
Jan. 1 to 5 and 10 to 14 } Piles over 45 ft. long }	$5\frac{3}{4}$	134	5,785	$23\frac{3}{10}$	1,006	$212.57	$0.0367
Jan. 5 to 10 and 14 to 31 .	$14\frac{1}{2}$	364	21,535	$25\frac{1}{10}$	1,485	539.61	0.02506
Feb. 1 to 28.	$19\frac{3}{4}$	379	25,036	$19\frac{1}{5}$	1,268	747.74	0.0298
March 1 to 5	$3\frac{1}{4}$	73	4,789	$22\frac{1}{2}$	1,473	135.75	0.0284

1737. Record Tables of Progress and Cost of Pile Driving.—The penetration of the pile was not measured until the rate of sinking indicated firm bottom, after which the penetration was measured for the last twenty or thirty blows, in sets of ten consecutive blows. In all cases the piles were driven until the requirements of the specifications were met, viz., a 20-foot fall of a 2,000 lb. hammer to cause a penetration not to exceed 1 inch. The notes relating to the size and driving of the pile were taken by the inspector at the time, the elevations by the engineer afterwards. A profile was then made up from these notes, and the piles ordered according to the lengths measured upon this profile. This scheme for estimating piling from actual tests proved a complete success, there being few discrepancies between the material in place and that ordered. The waste of material was consequently reduced to a minimum.

TABLE 43.

PRICES OF TRESTLE MATERIAL IN DIFFERENT SECTIONS OF NORTH AMERICA.

Material.	Texas.	Virginia.		Indiana.	Washington.	Halifax Harbor.
	1888.	1889.	1890.	1879–81.	1888.	1884–85.
Average penetration of piles on land				12 ft.		
Piles per lineal foot in place	35c.			25c.		
Round timber per lineal foot erected (round timber trestle)					9c.	
Dimension timber per M., B. M., erected....	$40				$23	Hemlock $16.47
Oak timber per M., B. M., erected..........		$30	$30	$25 to $30		
Pine timber per M., B. M., erected.........				$13 to $16		$26
Heart pine (Va. pine) per M., B. M., erected		$30	$30			
Cattle-guard timber per M., B. M., erected..	$30					
Bolts and nuts per lb.				$5\frac{1}{2}$c.	6c. to 7c.	

A permanent record of each structure should be made in detail during construction for the future use of the maintenance-of-way department. An excellent form of such a record, and the one used on the above work, is given here.

This gives actual cost of driving after the piles were delivered at the pile driver, but it is a very low average of cost, the work being done by the firm of Winston Bros., of Minneapolis, noted for their energy and excellence of plant equipment.

In making approximate estimates of cost of piling and trestles, when exact data are not available, the preceding table of cost will serve as a safe guide, as it is based on actual contract prices.

1738. Capping Piles.—When a floating pile driver is used, the sawing off and capping of the piles may follow the

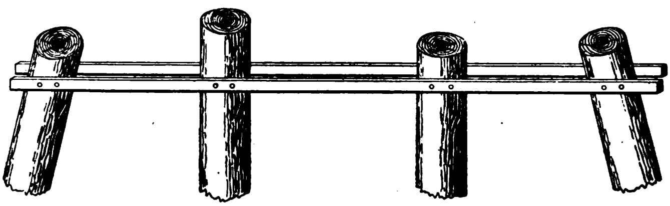


FIG. 557.

driving, at the convenience of the contractor, though it is better to follow the driving closely with the caps and stringers. When a land driver is used, each bent must be cut off and capped and timbers laid before the driver can advance to the next bent. As soon as a bent of piles is ready for cutting off, the height of the top of pile is given with an instrument, and a narrow, straight-edged strip of board (ordinary roofing lath serves well) is nailed on each side of the bent, with its top edge at the proper height for cutting off. (Fig. 557.) The cutting off is best done with a cross-cut saw worked by two men. If the piles are tenoned to the caps, the cutting necessary to form the tenon is done with the cross-cut saw.

1739. Caps may be fastened to the piles in three different ways, viz.: By mortise and tenon, by drift bolts, or by dowels. For *solid caps*, a tenon 3 inches thick, 8 inches wide, and 5 inches long is a good size (see Fig. 558). The top edges of the tenon should be chamfered and the mortise and tenon made so as to fit snugly. The parts are held together by means of wooden pins, called treenails. Treenails are from 1 inch to 1½ inches in diameter, and slightly tapering (see Fig. 558). They should be made of hard wood, oak or locust to be preferred. The hole made in the cap to receive the pin should be spaced a little further from the base of the cap than the hole in the tenon from the tenon shoulder, so that in driving the pin, the parts will be drawn together. Iron bolts or pins should never be used in place of wooden pins. Instead of crowding or drawing the parts together, the iron punches or cuts away any wood which lies in its path, merely increasing the size of the hole.

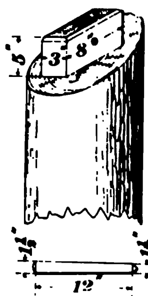


FIG. 558.

1740. When drift bolts or dowels are used, the piles are cut off level, and holes are bored in both cap and pile to receive the drift bolt or dowel. Sometimes two drift bolts or dowels are used at each pile, but commonly only one,

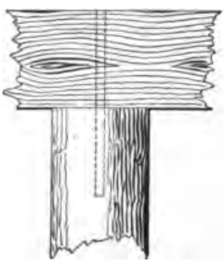


FIG. 559

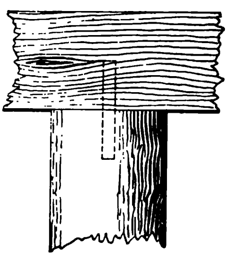


FIG. 560.

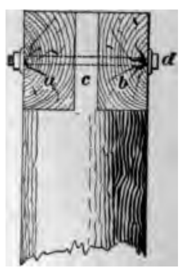


FIG 561.

which is amply sufficient. A hole is first bored through the cap into the pile head to receive the drift bolt, which should be somewhat larger than the hole, so that in driving, every cavity in the hole may be completely filled (see Fig. 559).

1741. Dowels are of shorter length than drift bolts and extend only about half way through the caps (see Fig. 560).

Another method of fastening caps to piles, and one which is rapidly growing in favor, is by means of split caps, shown in Fig. 561, in which the cap, instead of being a single piece of timber, consists of two pieces, each half the size of the single piece.

For example, instead of using for the cap a single stick of timber 12 inches by 12 inches, as shown in Figs. 559 and 560, we substitute two pieces *a* and *b* (Fig. 561), each 6 inches by 12 inches. A tenon *c*, 3 inches wide and extending the full width of the pile, is formed at its top, and a cap is placed on each shoulder against the tenon. A $\frac{3}{4}$-inch bolt *d* is passed through the caps and tenon, holding them firmly in place. The caps should not be notched, and the piles should be sawed off smooth and level, so as to afford a good bearing for the caps. Some of the advantages claimed for split caps are the following:

1st. On account of smaller size, better timber can be obtained at less cost.

2d. Repairs can be made with ease and great economy of time and labor.

3d. Traffic need not be interrupted nor endangered while repairs are being made.

4th. The caps may be replaced without cutting or injuring any other part of the structure.

5th. Economy in material, because it is not necessary to replace the whole cap unless both sticks are decayed, but only that part which is no longer in a serviceable condition.

FRAMED BENTS.

1742. Foundations.—Framed bents are composed entirely of sawed timber, and are placed upon a foundation, the objects of which are to ensure stability to the structure, and, by raising it from the ground, to prolong its life. All timber placed in direct contact with the ground partakes of

all its changing conditions of drouth and moisture, which soon induce decay. It is also desirable that the foundation should be as little affected by changes of temperature and moisture as possible. Among the various kinds of foundations used for trestle bents are the following: *masonry*, *pile*, *sub-sill*, *grillage*, *crib*, *solid rock*, and *loose rock*.

1743. Masonry foundations are the best. They are ordinarily composed of rubble masonry, laid either in lime or cement mortar. The latter is recommended, as it is not affected by moisture.

Suitable masonry foundations are shown in Figs. 562 and 563. In northern latitudes, trenches at least 12 inches in depth should be excavated for these foundations, to prevent

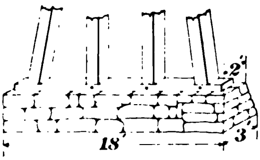


FIG. 562.

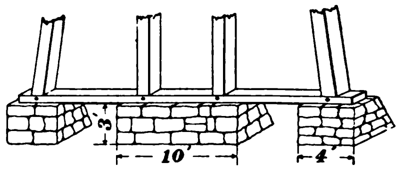


FIG. 563.

their being heaved by hard freezing. In exposed localities, where the freezing is more severe, it may be necessary to excavate the foundation trenches to a depth of 2 feet.

It is bad policy to use irregularly shaped stone, especially cobble stone, in building trestle foundations. The continual jar caused by passing trains is liable to seriously injure masonry of an inferior quality. *Dry* rubble, if built of long stones with horizontal beds, and well bonded, is much superior to mortar rubble of poor quality. The foundation walls shown in Figs. 562 and 563 are supposed to be laid in foundation pits 12 inches deep, and to extend 2 feet above the surface of the ground. The ends of the wall should be vertical, and the sides battered about 2 inches to the foot.

When pile foundations are employed for marshy ground of not too great depth, it is a good plan to allow the piles to extend far enough above the surface of the ground to form a bent, which is capped and a framed bent placed on top of

it. Where the trestle crosses a waterway, it is good practice to place a framed bent upon a pile foundation of such height as to remain always under water. The decay due to alternate wetting and drying is thus confined to the framed portion, which can easily be renewed.

1744. Sub-sills, or **mud-sills,** are blocks of timber placed under the main sills to raise them above the ground and so prevent decay. Some recommend planks 3 or 4 inches in thickness, but 12-inch by 12-inch timber is far better, and the additional cost is trifling compared with the solidity of foundation and security against decay. The sills and subsills should be fastened together, to prevent the latter from being displaced. As the strain is slight, 6-inch cut spikes,

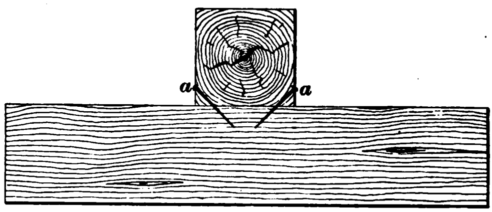


FIG. 564.

driven as shown at *a*, *a*, in Fig. 564, will serve for a fastening.

1745. A **grillage** of timber may be employed as a foundation when the trestle crosses a marsh extending to a great depth, but covered by a layer of earth possessing considerable supporting power. Such marshes are frequent in Canada and the States bordering on Canada. The grillage may be constructed either of sawed or round timber, according to which is the most available. The grillage shown in Fig. 565 was employed on the Northern Adirondack Railroad in crossing a subterranean lake. The lake was covered with earth to the depth of several feet and overgrown with brush and timber, but was unsafe for an embankment. The longest piles failed to reach bottom, and the grillage shown in the figure was employed. Each bent was supported by four logs or rangers laid lengthwise the bent, and cross-tied

by short logs which were drift-bolted to the rangers. The logs were notched at each intersection, as shown in the detail at *A*. The tops of the cross logs were adzed at their middle to a common level to receive the bent sills which were drift-bolted to the grillage. By this means the weight of the trestle and trainload was distributed over a considerable area. Though the road has been in operation more

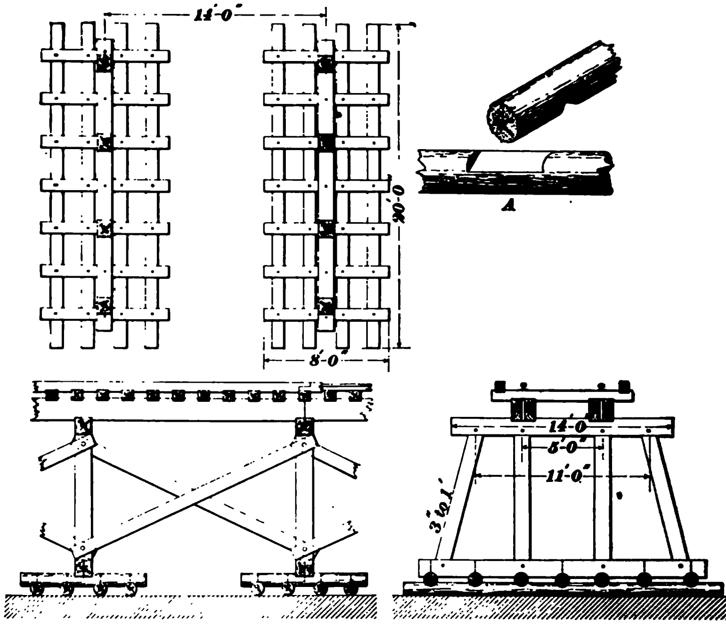


FIG. 565.

than a dozen years, no considerable settlement has taken place.

1746. Cribs may be employed for foundations where the ground is very sidling, or they may be used as a substitute for masonry foundations where the line crosses or borders on streams with rapid currents. At such points timber and cobble stones for ballast are often to be had for the asking, when masonry would prove very expensive.

A crib suitable for such foundations is shown in Fig. 566.

The crib is of pyramidal form and built entirely of round timber, notched together as shown in Fig. 565. On side hill ground, the surface is broken up into steps, as shown in the figure. The logs are drift-bolted together at the joints, and the enclosed spaces filled with stone. The crib should be long enough at the top to contain the sills, after full

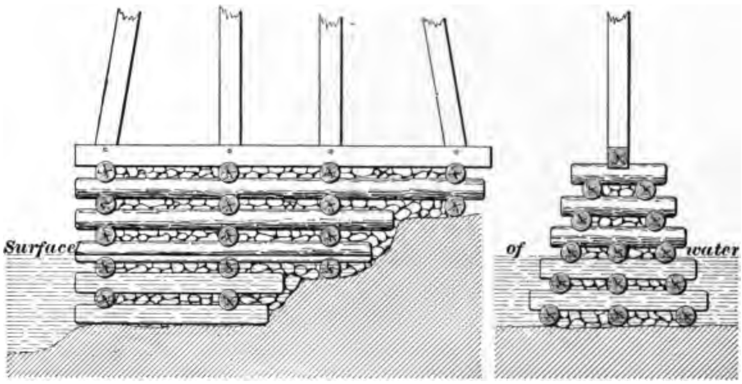


FIG. 566.

allowance has been made for the batter posts. This makes a cheap and substantial foundation, and it can be easily built in a swift current of water.

1747. If the surface is **solid rock,** all that is necessary in preparing a foundation is to smooth off a place for each post to stand on. The readiest way to fasten each post is by means of a dowel, which should reach 5 or 6 inches into the rock and an equal distance into the post. In some instances, holes are blasted into the surface rock, and the posts stood in the holes. After the posts are fastened together, forming a bent, the vacant space about the foot of each post is filled with rich cement mortar. When such foundations are used, the system of bracing should be ample, especially where the trestle is built on a side hill requiring posts of much greater length on the lower than on the upper side.

1748. Loose Rock.—Where masonry foundations would prove too costly, satisfactory foundations may be

made of loose rock. These are made by excavating a short trench directly under each post, as shown in Fig. 567.

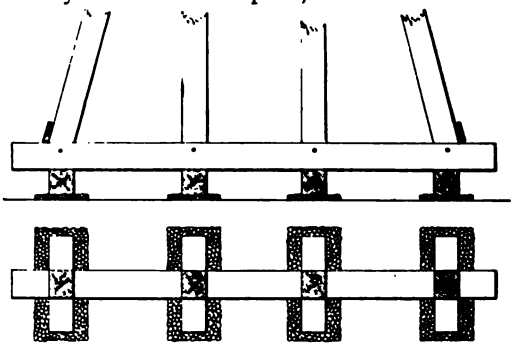


FIG. 567.

These trenches are filled rounding full of broken stone, and sub-sills placed upon them, forming the supports for the sills. If water accumulates in the trenches, it may be drained off by digging shallow open ditches around the foundations and leading them away to lower ground. This will at least save the sub-sills from contact with water and so preserve them from rapid decay.

1749. Drip Holes.—The tendency of water to accumulate in mortises hastens decay of the timbers. To prevent this, every mortise forming a receptacle for water should be provided with a drip hole ½ inch in diameter, bored with a downward inclination from the bottom of the mortise to the outside of the timber. Two methods of boring drip holes are shown in Figs. 568 and 569.

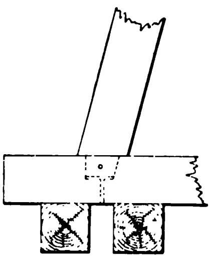


FIG. 568.

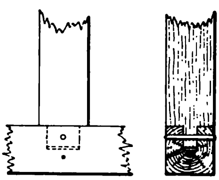


FIG. 569.

There are usually four posts to a bent; two vertical, or plumb, posts, and two inclined, or batter, posts. The standard dimensions of trestle posts are 12 inches by 12 inches, though other dimensions are sometimes used. The plumb

TABLE 44.

LENGTH OF BATTER POSTS. BATTER 3 IN. PER FOOT.

Distance Between Cap and Sill.		Length of Stick. Shoulder to Shoulder.		Length of Stick. Stick with Square Ends.		Length of Stick. With Two 5-in. Tenons.		Distance Between Cap and Sill.		Length of Stick. Shoulder to Shoulder.		Length of Stick. Stick with Square Ends.		Length of Stick. With Two 5-in. Tenons.	
ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
3	0	3	1	3	4	4	2	23		23	8½	23	11½	24	9½
3	6	3	7⅛	3	10⅛	4	8⅛	23	6	24	2⅝	24	5⅝	25	3⅝
4		4	1½	4	4½	5	2½	24		24	8⅞	24	11⅞	25	9⅞
4	6	4	7⅝	4	10⅝	5	8⅝	24	6	25	3	25	6	26	4
5		5	1⅞	5	4⅞	6	2⅞	25		25	9¼	26	0¼	26	10¼
5	6	5	8	5	11	6	9	25	6	26	3⅜	26	6⅜	27	4⅜
6		6	2¼	6	5¼	7	3¼	26		26	9⅝	27	0⅝	27	10⅝
6	6	6	8⅜	6	11⅜	7	9⅜	26	6	27	3¾	27	6¾	28	4¾
7		7	2½	7	5½	8	3½	27		27	10	28	1	28	11
7	6	7	8¾	7	11¾	8	9¾	27	6	28	4⅛	28	7⅛	29	5⅛
8		8	3	8	6	9	4	28		28	10⅜	29	1⅜	29	11⅜
8	6	8	9⅛	9	0⅛	9	10⅛	28	6	29	4½	29	7½	30	5½
9		9	3⅜	9	6⅜	10	4⅜	29		29	10¾	30	1¾	30	11¾
9	6	9	9½	10	0½	10	10½	29	6	30	4⅞	30	7⅞	31	5⅞
10		10	3⅝	10	6⅝	11	4⅝	30		30	11	31	2	32	0
10	6	10	9⅞	11	0⅞	11	10⅞	30	6	31	5¼	31	8¼	32	6¼
11		11	4	11	7	12	5	31		31	11½	32	2½	33	0½
11	6	11	10¼	12	1¼	12	11¼	31	6	32	5⅝	32	8⅝	33	6⅝
12		12	4½	12	7½	13	5½	32		32	11⅞	33	2⅞	34	0⅞
12	6	12	10⅝	13	1⅝	13	11⅝	32	6	33	6	33	9	34	7
13		13	4¾	13	7¾	14	5¾	33		34	0¼	34	3¼	35	1¼
13	6	13	11	14	2	15		33	6	34	6⅜	34	9⅜	35	7⅜
14		14	5⅛	14	8⅛	15	6⅛	34		35	0½	35	3½	36	1½
14	6	14	11⅜	15	2⅜	16	0⅜	34	6	35	6¾	35	9¾	36	7¾
15		15	5½	15	8½	16	6½	35		36	0⅞	36	3⅞	37	1⅞
15	6	15	11¾	16	2¾	17	0¾	35	6	36	7⅛	36	10⅛	37	8⅛
16		16	5⅞	16	8⅞	17	6⅞	36		37	1¼	37	4¼	38	2¼
16	6	17	0	17	3	18	1	36	6	37	7½	37	10½	38	8½
17		17	6¼	17	9¼	18	7¼	37		38	1⅝	38	4⅝	39	2⅝
17	6	18	0½	18	3½	19	1½	37	6	38	7⅞	38	10⅞	39	8⅞
18		18	6⅝	18	9⅝	19	7⅝	38		39	2	39	5	40	3
18	6	19	0⅞	19	3⅞	20	1⅞	38	6	39	8¼	39	11¼	40	9¼
19		19	7	19	10	20	8	39		40	2⅜	40	5⅜	41	3⅜
19	6	20	1¼	20	4¼	21	2¼	39	6	40	8⅝	40	11⅝	41	9⅝
20		20	7⅜	20	10⅜	21	8⅜	40		41	2¾	41	5¾	42	3¾
20	6	21	1½	21	4½	22	2½	40	6	41	9	42	0	42	10
21		21	7¾	21	10¾	22	8¾	41		42	3⅛	42	6⅛	43	4⅛
21	6	22	1⅞	22	4⅞	23	2⅞	41	6	42	9⅜	43	0⅜	43	10⅜
22		22	8⅛	22	11⅛	23	9⅛	42		43	3½	43	6½	44	4½
22	6	23	2¼	23	5¼	24	3¼	42	6	43	9¾	44	0¾	44	10¾

posts should be spaced from 4 to 5 feet between centers, and the batter posts 11 feet from center to center at the top. The inclined posts should have a batter of 3 inches to the foot. This gives a broad base, adding considerably to the stiffness and stability of the structure. It is poor economy to stint the dimensions of trestle timbers. It is far better to have an excess of strength than a lack of it, and the addition of one or two inches to any dimension involves but a slight increase in cost and makes safety certain.

Table 44 gives the length of batter posts for different heights at an inclination of 3 inches per foot.

The first column gives the vertical height of the bent from top of sill to base of cap. The second column gives the length of the post as measured along either edge after the end is cut to the proper angle. The third column gives the length of the timber with square ends required to cut the post, and the fourth column the length of stick required to give a tenon 5 inches long on both ends of post.

The table is used as follows: The height of a bent from base of sill to top of cap is 25 ft., the cap and sill are each 12 in. by 12 in.; what length of timber is required for posts to batter 3 in. to the foot and give a 5-in. tenon at both ends? Deducting 2 ft. from 25 ft., the total height of bent, we have 23 ft., the distance between cap and sill. Referring to the table we find in the fourth column opposite 23 ft., 24 ft. $9\frac{1}{2}$ in., the required length of the posts.

1750. Batter post templates set at the proper angle are very convenient for cutting the ends of posts. A piece of $\frac{1}{2}$-inch hard wood board cut to the proper angle with a 1-inch cleat fastened to the edge of the board, to fit against the edge of the batter post, serves the purpose well. A template of this description is shown in Fig. 570.

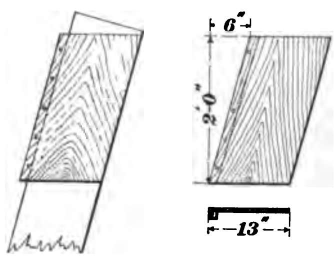


FIG. 570.

Some designers place the plumb and batter posts so as to touch each other where they meet the caps (Fig. 571).

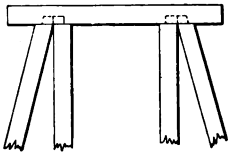


FIG. 571.

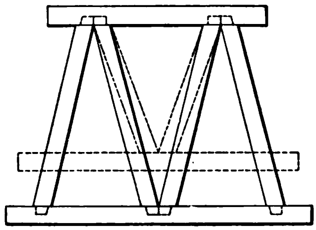


FIG. 572.

When all the posts are battered, the distance between them at the top is fixed.

The outside posts have a uniform batter irrespective of height, while the inside posts change their batter with each change of height (Fig. 572).

The caps, if solid, should be of not more than 12-in. by 12-in. timber. In a majority of cases 10-in. by 10-in. timber would serve equally well, often insuring better timber and resulting in considerable saving of material. There are several different ways of joining the sills, posts, and caps together, but only three are in general use, viz., by mortise and tenon, by drift bolts, and by dowels.

A tenon 3 inches thick, 8 inches wide, and 5 inches long is a good size. The mortise should be about $\frac{1}{2}$ inch deeper than the length of the tenon and well finished, so that the tenon will fit snugly. In boring the hole for the treenail, the same precaution should be taken with framed bents as with pile bents. All mortises so placed as to hold water should be provided with drip holes.

1751. The use of drift bolts in connecting cap and sill with posts is shown in Fig. 573, and dowel connections in Fig. 574.

Two drift bolts are required to fasten a post to the sill and one to secure it to the cap. A hole must be bored for each drift bolt, two sizes of holes being used. The first hole is slightly smaller than the drift bolt, the second hole still smaller. The drift bolts used for these connections are

either of square or round iron. If square, ¾ inch will answer, or iron of equivalent weight, if round. Dowels are usually of ¾-inch round iron.

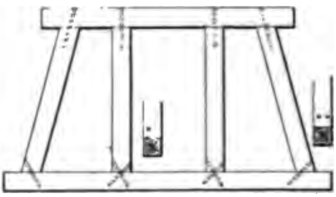


FIG. 573.

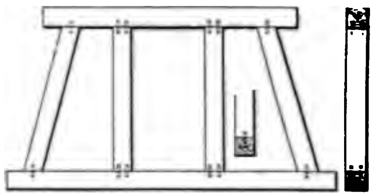


FIG. 574.

Split caps and sills are preferred on some roads, and when used, the connections with the posts are made similar to split cap connections of pile trestles (see Fig. 561).

It is customary to notch both cap and sill at the post joints. Both square and beveled notches are employed (see Figs. 575 and 576), though the former (Fig. 575) is to be preferred.

FIG. 575.

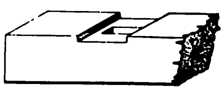


FIG. 576.

Bents should be uniformly spaced, the distance between centers of bents being from 12 to 16 feet, depending upon the character and cost of timber. Spans from 12 to 14 feet are most common.

FLOOR SYSTEM.

1752. Corbels.—Corbels are placed lengthwise the stringers and between them and the caps. They are not favored by the best designers, and do not appear in most trestles of recent construction. Corbels are usually from

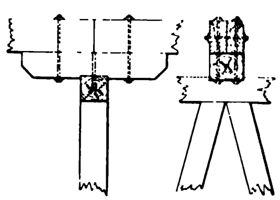


FIG. 577.

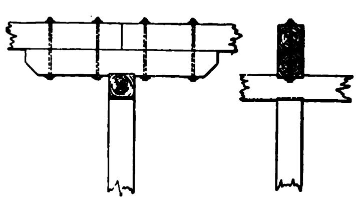


FIG. 578

4 to 8 feet long, extending equal distances each side of the cap. They are usually notched down on the caps, and often doweled to them. The stringers are bolted to the corbels, which virtually shorten the span, so that lighter stringers may be used with corbels than without them. If, however, the cost of the corbels was expended in increasing the size of the stringers, an equally strong and considerably simpler structure would be the result. Two common types of corbels are shown in Figs. 577 and 578.

1753. Stringers.—A stringer is usually placed directly beneath each rail, and instead of a single piece of timber, it should be composed of two or more smaller pieces which combined possess the requisite strength. Smaller sizes of timber are less expensive and less liable to conceal damaging defects. These pieces should be separated from each

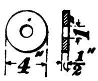


FIG. 579.

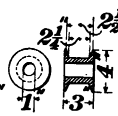


FIG. 580.

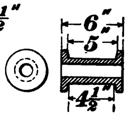


FIG. 581.

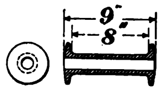


FIG. 582.

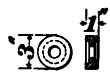


FIG. 583.


FIG. 584.

other either by cast-iron *separators*, or by *packing-blocks*, or both. The distance apart at which stringers are placed varies widely, ranging from nothing to 10 or 12 inches. A safe distance is 3 inches, the space being occupied by both a separator and a packing-block. Common types of separators are given in Figs. 579 to 584.

The prime object of the separator is to hold the stringers apart from each other, and so prevent the accumulation of moisture, which would soon induce decay.

1754. Packing-blocks are pieces of plank from 4 to 6 feet in length placed between the stringers and over the caps. They extend equally in both directions from the cap, and some contain a notch which fits down over the cap. They serve to strengthen the connection between cap and stringer, and, together with the separators, maintain the space between the stringers.

There are several styles of packing-blocks, among which are those shown in Figs. 585, 586, and 587. Of these the type shown in Fig. 587 is recommended. This block is 6

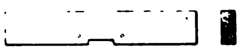


FIG. 585.

FIG. 586.

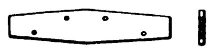


FIG. 587.

feet in length and 2 inches in thickness. Four $\frac{3}{4}$-inch bolts pass through both stringers and packing-block. Separators $\frac{1}{2}$ inch thick (see Fig. 579) are placed between the stringer and packing-block, the stringer or packing-bolts passing through the separators and holding them in place.

1755. Wherever practicable, the stringer should be long enough to cover two spans, so as to break joints on the caps. Some provision should be made for holding the stringers firmly in place. This is usually effected by drift-bolting the stringers to the caps. One objection to this mode of fastening stringers is the great difficulty in removing the bolts when repairs are to be made. To obviate this difficulty, pieces of 3-inch by 12-inch plank of such length as to give to the stringers the proper spacing are placed between the stringers, being fastened to the caps by spikes or lag-screws. These pieces of plank are called spreaders, and they are already much in favor.

1756. Stringer Joints.—There are many different styles of stringer joints employed on American roads,

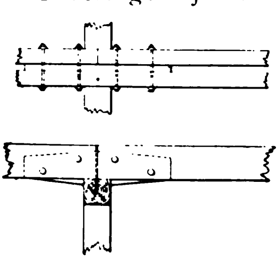


FIG. 588.

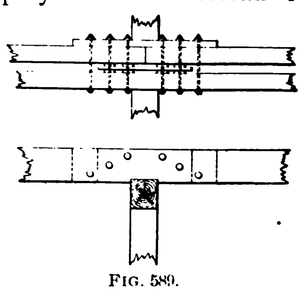


FIG. 589.

among which those shown in Figs. 588 to 591 have especial merit.

The joint shown in Fig. 588 is especially recommended. It is simple, strong, and withstands decay. In case the supports should settle so as to practically double the span, the

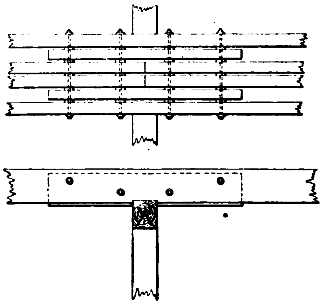


FIG. 590.

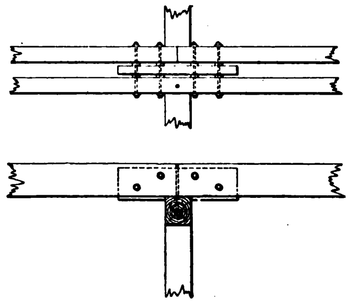


FIG. 591.

joint is so constructed as to best resist this strain. Any tendency to settle is at once counteracted by the packing-bolts, which must either break or split the stringer before the joint can fail. The strain is greatest on the lower bolts, which are placed furthest from the joint, where they are least likely to split the stringer. This joint would be improved by placing a separator, like that shown in Fig. 579, between each stringer and the packing-block. This would make the space between the stringers 3 inches.

To prevent longitudinal movement, stringers must be either notched down one inch on the caps or drift-bolted to them. All packing-bolts should be long enough to receive a *cast washer* under both head and nut. The difficulty of removing drift-bolts when making repairs has already been mentioned. By notching down the stringers on the caps, and by placing a spreader *a* between them (see Fig. 592), all lateral movement is prevented. The spreaders are fastened to the caps either by lag-screws or

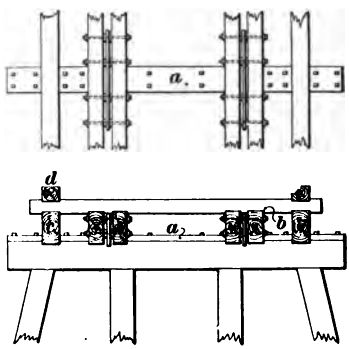


FIG. 592.

by spikes. By notching down the ties 1 inch on the stringers (see *b*, Fig. 592), the spacing of the stringers is maintained, and the ties held rigidly in place.

1757. Size of Stringers.—The size of the stringer pieces in section will depend upon the length of the span and the character of the traffic. Two is the number of pieces generally used. They should be of sufficient dimensions to carry the heaviest train load without any considerable deflection. A stringer more used on American roads than all others has the following dimensions: Width, 8 inches; depth, 16 inches, and length varying from 24 to 28 feet. Each rail is supported by two such pieces, making four for a complete span. Yellow or Southern pine is generally used, though white pine, Oregon pine, spruce, or even hemlock of these dimensions, if sound, will carry any train load ordinarily hauled on American lines. Dimensions of track stringers used on the Pennsylvania Railroad are given in Table 45.

TABLE 45.

TRESTLE STRINGERS, PENNSYLVANIA RAILROAD STANDARD.

Dimensions of Stringers.

Clear Span.	Number of Pieces under Each Rail.	Width of Each Piece.	Depth of Stringers.
10 ft.	2	8 in.	15 in.
12 ft.	2	8 in.	16 in.
14 ft.	2	10 in.	17 in.
16 ft.	3	8 in.	17 in.

1758. A **jack-stringer** composed of a single piece, and shown at *c* in Fig. 592, is often placed near the ends of the ties and directly beneath the guard-rail, the object of which is to afford additional support to the ties in case of

derailment. Without this support the ties are likely to be broken by a derailed engine, and a total wreck follow, while with it, providing the guard-rail holds, the engine and train are likely to remain on the trestle. This greatly increases the factor of safety. The jack-stringers should reach over two spans, breaking joints alternately, and be drift-bolted to the caps. The ends of the stringers should abut against each other, though there are a few instances to the contrary.

1759. Ties.—Trestle ties vary in both section and length. A good size is 7 in. by 8 in. by 12 ft. in length.

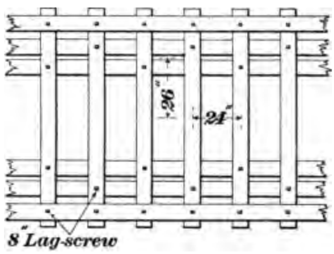


FIG. 593.

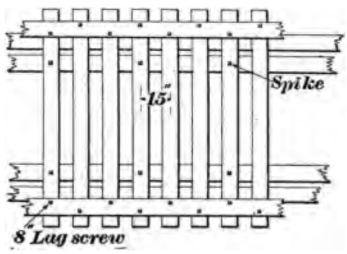


FIG. 594.

This length provides for a jack-stringer. Many ties are only 9 feet in length, while others are 10 feet. They are spaced from 12 to 24 inches between centers, though 15 inches

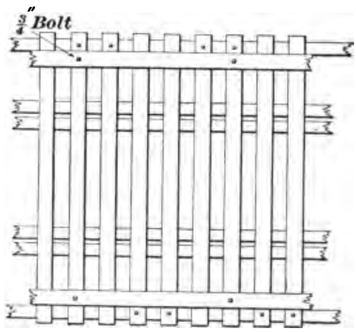


FIG. 595.

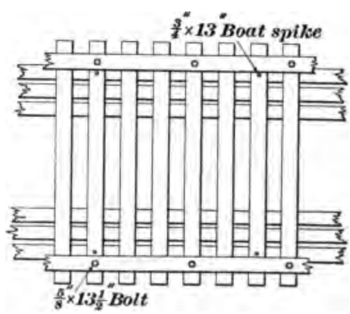


FIG. 596.

should be the limit. The reason for placing them close together is that, in case of derailment, ties closely spaced

afford a fairly continuous support for the car wheels, especially the driving wheels, while those widely spaced allow the wheels to drop between, and the ties are torn up, and a wreck is likely to follow. On some roads, none of the ties are fastened to the stringers; on others, every fifth, or even every other, tie is fastened, spikes or lag-screws being generally used for the purpose. Dowels are used for tie fastenings, but only in a limited way, the only important road employing them being the Louisville and Nashville Railroad (Fig. 597). Four different standard floor systems are given in Figs. 593 to 596, showing the arrangement and mode of fastening cross-ties. In the Pennsylvania standard, the wide spaces between the ties are a serious objection, as in case of derailment it renders wreck almost certain. The dimensions and arrangement of ties in Fig. 594 are especially recommended. Ties should always be notched down 1 inch over the stringers. Notching prevents any lateral movement and strengthens the floor system.

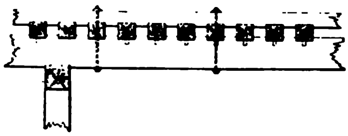


FIG. 597.

1760. Guard-Rails.—Guard-rails are an important part of the trestle. Their purpose is twofold, viz., first, to prevent a train from leaving the bridge in case of derailment, and, second, to maintain the spacing of the ties and add weight and strength to the floor system. Where a jack-stringer is used, the guard-rail is placed directly above it. Guard-rails should be notched down upon the ties, usually 1 inch, and fastened to them either with bolts or lag-screws. Guard-rails in section should be not less than 6 by 8 inches, the length depending on the available supply, but no length under 16 feet should be used. Commonly the guard-rails and cross-ties are of the same sized timber, 7 by 8 inches being a standard size, the lengths running from 20 to 24 feet. They are spliced in a variety of ways. Various forms of splices are shown in Figs. 598 to 601. The halved joint (Fig. 598) is recommended as simple and effective.

Joints should come directly over a tie and be broken, i. e., a joint on one guard-rail should be on line with the middle point of the opposite guard-rail. Each joint should be fastened with either a bolt or a lag-screw. Bolts are to be much preferred to lag-screws for fastening guard-rails to ties. Lag-screws tear the fiber of the wood, and form cavities which hold moisture and induce decay. The best plan is to bolt every fourth or fifth tie to the guard-rail, and

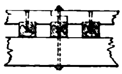
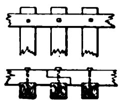
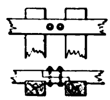





FIG. 598. FIG. 599. FIG. 600. FIG. 601. FIG. 602. FIG. 603.

spike the remaining ties with 10-inch boat spikes. A *punched* washer should be put under the head of each lag-screw. It is a waste of time and an injury to the timber to countersink the heads of bolts or lag-screws. The holes form receptacles for water, which soon induces decay. A 3 to 3½-inch cast washer should be placed under the head and nut of each bolt, the nut being placed *up* so as to make inspection and repairs easy.

1761. The ends of the guard-rail should be beveled, as shown in Fig. 602 or 603. The guard-rails should extend from 20 to 30 feet from the trestle on to the embankment. They should be flared outwards so that at their extremities they will be from 3 to 4 feet from the rails. The object of flaring the guard-rails is to assist any car which may have been derailed on the embankment in passing the trestle in safety (see Fig. 604). On some roads, in addition to these flaring guards, bumping posts are placed near the end of the embankment, but their value is not generally admitted.

An additional safeguard, and one in general use on some lines, is an inner guard-rail of the same section as the main rail, placed 2½ inches inside the rail. Objection is made by some to this form of guard-rail on the ground of its forming

a lodgment for detached pieces of the truck, such as brake shoes, box lids, etc., causing the wheels to mount the rails. The tendency of wheels to mount the wooden guards may be

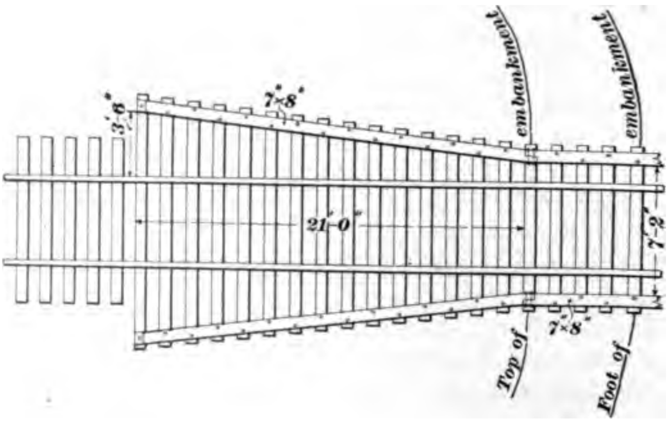


FIG. 604.

prevented by fastening a strip of angle iron on the upper inside edge of the guard-rail.

1762. Fastening Down Floor System.—There are several different methods of fastening the floor system down to the bents, some of which have already been mentioned. The method generally adopted is to drift-bolt the stringers to the caps (Fig. 605). The only objection to this method has already been stated, viz., the difficulty of removing the bolts when making repairs. This mode of fastening the floor system has the merits of simplicity and security, and is more used than all others. Another

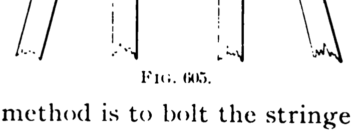


FIG. 605.

method is to bolt the stringers to the caps, in which case the posts must be so spaced as to allow the bolt to pass through the cap. On some roads the stringers are not fastened to the caps, the weight of the floor system being depended

upon to hold them down. In such cases the stringers must be notched down 1 inch upon the caps and spreaders, as shown in Fig. 592, used to prevent lateral movement.

BRACING.

1763. Sway-Bracing.—Pile or framed bents under 10 feet in height seldom require any sway-bracing. Bents from 10 to 20 feet in height require a single **X** brace of 3-inch by 10-inch planks extending diagonally from the upper corner of the cap to the foot of the opposite pile or to the outside corner of the sill, if a framed bent (see Fig. 606). For bents from 20 to 40 feet in height, two **X** braces separated by 3-inch by 10-inch horizontal planks spiked to both sides of the bent, as shown in Fig. 607, afford ample bracing. There are two methods of fastening the sway-braces, both in general use. In one, the sway braces are fastened to the piles or posts with $\frac{3}{4}$-inch bolts and cast washers, as shown in Fig. 606; in the other, they are spiked with $\frac{1}{2}$-inch by 8-inch boat spikes. Bolt fastenings may be easily removed without damaging the braces, which may be used a second time, if not decayed. Spikes, on the other hand, are difficult to draw, and sway-braces are often split or broken in removing them from the bents. However, second-hand trestle material is of little value, and as spikes are a sure fastening and cheaper and more expeditious than bolts, they are to be recommended.

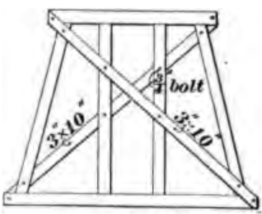


FIG. 606.

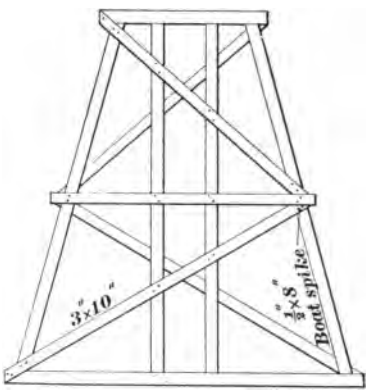


FIG. 607.

When the piles of a bent are out of line so that the sway-brace can not lie flat, they should either be hewn so that

spiked or bolted to place, they should fit snugly and be at least *slightly strained.*

1767. Trestles on Curves.—Wherever possible, *curved trestles* should be avoided. The additional stress due to the centrifugal force of heavy trains at high speed is a severe tax upon a structure, and the locating engineer should, if possible, so modify his line as to place all trestles on

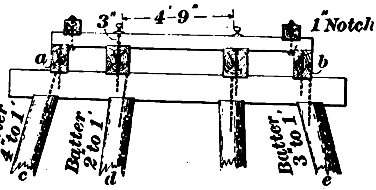


Fig. 608.

tangents. Circumstances, however, sometimes render the curved trestle a necessity, in which case the outer posts must have an increased batter and the outer rail its proper elevation.

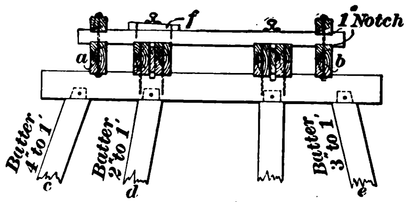


Fig. 609.

There are various methods of elevating track on curved trestles, three of which are shown in Figs. 608, 609, and 610. In Fig. 608 the elevation is effected by cutting off the piles or framing the posts to such lengths as will afford the requisite elevation. This is the simplest and easiest method of elevating the outer rail of a trestle. There are no shims to get out of place or need renewing, and there is no increase in cost above that of a trestle on a straight line.

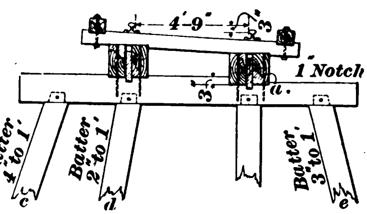


Fig. 610.

In Fig. 609 the outer rail is elevated by means of a shim *f*, which is placed under the rail and fastened to the tie with cut spikes. The weak point in this mode of elevating the outer rail, aside from the cost of making and fastening the shims, is the accumulation of moisture under the shims, which induces their decay and the decay of the ties also.

In Fig. 610 the elevation is effected by cutting away a portion of the cap at *a* to an amount equal to the required elevation. The stringers are then placed in a horizontal position, as shown in the figure, and the notches in the ties beveled so as to fit the top of the stringers. In pile bents, the caps are usually drift-bolted to the piles, and in framed bents the connection is usually made with mortise and tenon. In all three methods, the stringers are drift-bolted to the caps. In Figs. 608 and 609, the jack-stringers *a* and *b* add considerable to the stability of the structures, and are an additional safeguard in case of derailment. The elevation of the outer rail in each case is 3 inches, and the degree of the curves 6 degrees. Both posts or piles *c*, *d* on the outside of the curve are battered, the outside one at a batter of 4 inches to the foot, and the next inside 2 inches to the foot. On the inside of the curve, only the outside posts or piles *c* of the bent are battered, and at the usual batter of 3 inches to the foot. If the trestle is a high one, it should be strengthened by additional bracing.

IRON DETAILS.

1768. Spikes.—There are two kinds of spikes used in trestle building, viz., **cut spikes** (Fig. 611), which are formed like ordinary cut nails and manufactured in the same way, and **boat spikes** (Fig. 612), which are forged from bars of wrought iron. Spikes of the same length are not necessarily of the same weight. Slender spikes are not suited for trestle building, as they are liable to bend and break, besides lacking in holding power. Those having good sized heads and bodies should always be used. Steel spikes are to be preferred to iron ones, as they are tougher and stronger.

FIG. 611.

FIG. 612.

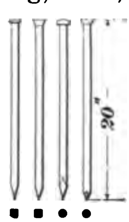


FIG. 613.

Boat spikes, shown in Fig. 612, have strong, well-formed heads, and are *chisel pointed*. They are used to fasten

guard-rails to ties, ties to stringers, and sway-bracing to the bents.

Table 46 gives sizes and weights and numbers of spikes in a keg of 100 pounds:

TABLE 46.

CUT SPIKES.

Length in Inches	No. in Keg of 100 lb.	Weight of One Spike, lb.	Length in Inches	No. in Keg of 100 lb.	Weight of One Spike, lb.
3	2,900	.0344	5½	850	.1176
3½	2,100	.0476	6	775	.1293
4	1,500	.0667	6½	575	.1739
4½	1,150	.0869	7	450	.2222
5	950	.1052	8	375	.2666

Table 47 gives the lengths of the different sizes of boat spikes, the approximate number of each in a keg of 150 pounds, and the weight of each.

1769. Drift Bolts.—Drift bolts commonly resemble boat spikes in shape, but they are much larger. The heads are less carefully shaped, and often they are used without either head or point, the bolts being simply sheared from rods to a proper length, and driven into the holes bored to receive them. The ordinary shapes are shown in Fig. 613. For fastening 12-inch caps to posts or piles, drift bolts of ¾-inch square or ⅞-inch round iron and 20 inches long are commonly used. They should always penetrate the last timber into which they are driven a sufficient distance to resist any legitimate pull or shock which will be placed upon them. Holes are always bored to receive drift-bolts. They should be of such size that, in driving, the fibers of the wood will fill all space not occupied by the bolt itself.

TABLE 47.

NUMBER OF BOAT SPIKES IN A KEG OF 150 POUNDS, AND WEIGHT OF A SINGLE SPIKE.

Thickness in Inches.	Length in Inches.														
	3	3½	4	4½	5	5½	6	6½	7	7½	8	8½	9	9½	10
$\frac{1}{4}$	1,910	1,585	1,326	1,025											
	.0785	.0946	.1093	.1463											
$\frac{5}{16}$	1,010	963	810	605	583		521								
	.1485	.1557	.1851	.2479	.2572		.2879								
$\frac{7}{16}$			542	503	461	423	402	321							
			.2767	.2982	.3253	.3546	.3731	.4673							
					340	312	298	280	261	240	223				
					.4117	.4839	.5033	.5357	.5747	.625	.6726				
							221	200	190	180	170	160	150	140	130
							.6787	.75	.7881	.8333	.8823	.9375	1.000	1.0714	1.1538
											140	130	120	110	100
											1.0714	1.1538	1.25	1.3636	1.500

Table 48 gives the weight of drift-bolts of the sizes commonly used:

TABLE 48.

WEIGHTS OF DRIFT-BOLTS.

Length in Inches.	Square Section.		Round Section.	
	$\frac{3}{4}$ in. sq.	1 in. sq.	$\frac{3}{4}$ in. diam.	1 in. diam.
	Lb.	Lb.	Lb.	Lb.
18	2.9	5.1	2.3	4.0
20	3.2	5.7	2.5	4.4
22	3.5	6.2	2.8	4.9
24	3.8	6.8	3.0	5.3
26	4.1	7.3	3.3	5.8

1770. The main value of drift-bolts lies in their holding power. A long series of experiments by the United States Engineer Corps, made while building the St. Mary's Canal locks, developed the following results:

The mean of from 150 to 200 experiments with round and square bolts, both smooth and ragged, in different-sized holes, shows that the resistance after having been driven seven months is 10 per cent. greater than the resistance immediately after driving, the different sizes and forms being strictly uniform.

The mean of 150 experiments under various conditions shows that the resistance to being drawn in the direction in which the bolts were driven is only 60 per cent. of their resistance to being drawn in the opposite direction; that is to say, the resistance to being drawn *through* is only 60 per cent. of the resistance to being drawn *back*. The mean of 50 experiments shows that smooth rods have a greater resistance than ragged bolts, both to being drawn through and also to being drawn back; that a *moderate ragging* reduces the holding power a little more than 25 per cent., and an *excessive ragging* reduces the holding power more than 50 per cent.

The best relation between the diameter of the bolt and that of the hole, as determined by one series of 60 experiments, shows that the holding power of a 1-inch round bolt in a $\frac{11}{16}$-inch hole is greater than in a $\frac{12}{16}$-inch or a $\frac{13}{16}$-inch hole, the resistance in a $\frac{12}{16}$-inch hole being 98 per cent. and that in a $\frac{13}{16}$-inch hole being 90 per cent. of that in a $\frac{11}{16}$-inch hole. Another series of 35 experiments makes the holding power of a 1-inch round bolt in a $\frac{12}{16}$-inch hole greater than in a $\frac{13}{16}$ or a $\frac{14}{16}$-inch hole, the first two being practically the same, and the last being only 85 per cent. of the first. For a $\frac{3}{4}$-inch round bolt four experiments with each size prove that the holding power of the bolt in a $\frac{10}{16}$-inch hole is about one quarter greater than in a $\frac{9}{16}$-inch or a $\frac{11}{16}$-inch hole. For a 1-inch square bolt, the holding power in a $\frac{14}{16}$-inch hole is only a trifle greater than in a $\frac{13}{16}$-inch hole, and about 20 per cent. greater than in a $\frac{15}{16}$-inch hole, as deduced from 20 to 40 experiments for each size of hole.

The holding power of a 1-inch square bolt in a $\frac{14}{16}$-inch hole was practically the same as for a 1-inch round rod in a $\frac{11}{16}$-inch hole. There is 25 per cent. more metal in the square drift-bolt and more labor is required in boring a $\frac{14}{16}$-inch hole than in boring a $\frac{11}{16}$-inch hole; hence, the round drift-bolt is 25 per cent. more efficient than the square one.

In the matter of pointing the bolts, experiment goes to prove that drift-bolts with a long, slender point have about 10 per cent. greater resistance than those with short, blunt points, the conclusion being that the blunt points tear the fiber of the wood, while the slender points crowd it aside, filling up the cavities of the hole, thereby increasing the friction of the bolt.

1771. Dowels.—In place of drift-bolts, short iron rods, either square or round, called **dowels**, are frequently used. They have neither point nor head, but are sheared from rods, care only being taken to make them straight. They are frequently used to fasten caps to posts, posts to sills, and ties to stringers. A common size of dowel for fastening caps to posts and posts to sills is $\frac{3}{4}$-inch round or square by 8 inches in length, weighing about 1 pound each.

Dowels of $\frac{5}{8}$-inch round iron, 5 inches in length, are well suited for fastening ties to stringers.

The following list gives the weight of 1-inch lengths of the various sizes of iron bars or rods commonly employed in this kind of work:

1 in. square	0.2806 lb.	$\frac{3}{4}$ in. diam. round	0.1240 lb.
1 in. diam. round	0.2204 lb.	$\frac{5}{8}$ in. square	0.1096 lb.
$\frac{7}{8}$ in. square	0.2149 lb.	$\frac{5}{8}$ in. diam. round	0.0860 lb.
$\frac{7}{8}$ in. diam. round	0.1687 lb.	$\frac{1}{2}$ in. square	0.0701 lb.
$\frac{3}{4}$ in. square	0.1579 lb.	$\frac{1}{2}$ in. diam. round	0.0551 lb.

1772. Bolts.—Bolts for holding the stringer pieces together, fastening the braces, guard-rails, etc., are commonly of $\frac{3}{4}$-inch round iron, their lengths, of course, depending upon the purpose for which they are to be used. The bolt heads should be well formed, and of good weight, and the threads right-handed and well cut.

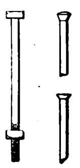


Fig. 614.

Bolt heads are of three forms—button heads, flat countersunk heads, and the ordinary square heads (Fig. 614). Square nuts with a thickness equal to the diameter of the bolt and length of side equal to twice the diameter of the bolt are the best. The outer top corners of both head and nut should be chamfered.

A cast-iron washer from 3 to $3\frac{1}{2}$ inches in diameter should be placed under the head and nut of all bolts. Holes of $\frac{1}{16}$ inch less diameter than the bolts are bored through the timber to receive the bolts to insure a close fit.

Table 49 gives sizes and weights of bolts, and though not exact, owing to the varying weights of heads, is amply close for *approximate estimates.*

In ordering bolts, the term *grip*, as sometimes employed, signifies the total thickness of the material to be held together; in other words, the distance between the inside faces of washers.

1773. Lag-Screws.—A lag-screw is a large wood screw which serves in place of a bolt. The head is shaped

TABLE 49.

APPROXIMATE WEIGHT OF BOLTS IN POUNDS, WITH SQUARE HEADS AND NUTS, INCLUDING BOTH.

Length Under Head in Inches.	Diameter in Inches.				
	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
6	0.59	1.01			
7	0.64	1.10			
8	0.70	1.19			
9	0.75	1.27			
10	0.81	1.36	2.10	3.05	4.23
11	0.86	1.44	2.22	3.22	4.45
12	0.92	1.53	2.35	3.39	4.67
13	0.97	1.62	2.47	3.55	4.89
14	1.03	1.70	2.59	3.72	5.11
15	1.08	1.79	2.72	3.89	5.34
16		1.87	2.84	4.06	5.56
17		1.96	2.97	4.23	5.78
18		2.05	3.09	4.40	6.00
19			3.21	4.57	6.22
20			3.34	4.74	6.44
21			3.46	4.90	6.66
22			3.59	5.07	6.88
23			3.71	5.24	7.10
24			3.83	5.41	7.32

like a bolt head, and an ordinary wrench may be used in fastening the screw in place. A hole of the full size of the shank of the screw is bored through the first timber and a much smaller one is bored for the balance of the distance through which the thread is to pass. A wrought or *punched* washer cut from sheet iron should be placed under the head of each lag-screw. The ordinary form of lag-screw is shown in Fig. 615.

FIG. 615.

1774. Washers.—Cast washers are largely used in trestle building. One should be placed under the head and nut of every bolt used in the structure. The more common forms of cast washers are shown in Fig. 616, and their

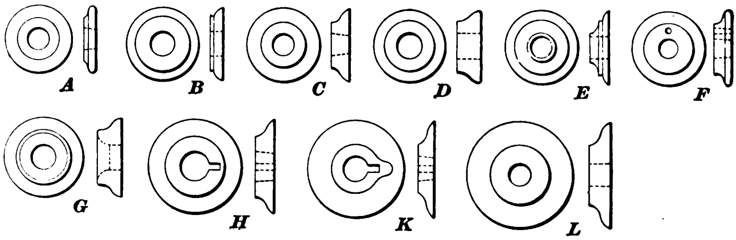


FIG. 616.

dimensions are given in Table 50. The solid washers are placed under the head and the slotted washers, or those

TABLE 50.

DETAILS OF CAST-IRON WASHERS.

Kind, Fig. 616.	Dimensions in Inches.			
	Diameter of Back.	Diameter of Face.	Diameter of Hole.	Thickness.
A	$2\frac{3}{4}$	$1\frac{3}{4}$	$\frac{7}{8}$	$\frac{1}{2}$
B	3	$2\frac{1}{4}$	1	$\frac{1}{2}$
C	3	$1\frac{3}{4}$	$\frac{7}{8}$	$\frac{3}{4}$
D	3	2	1	1
E	3	$1\frac{1}{8}$	$\frac{7}{8}$	$\frac{3}{4}$
F	3	2	$\frac{3}{4}$	$\frac{3}{4}$
G	$3\frac{1}{4}$	$2\frac{1}{4}$	1	$\frac{3}{4}$
H	$3\frac{7}{8}$	$2\frac{1}{2}$	$1\frac{3}{16}$	$\frac{3}{4}$
K	4	2	1	$\frac{5}{8}$
L	$4\frac{3}{8}$	$2\frac{3}{8}$	$\frac{7}{8}$	$\frac{7}{8}$

having a second hole, under the nut. The purpose of the slot, or second hole, is to provide for locking the nut. After

the nut is well tightened, a nail is driven in the slot or hole with the head projecting far enough above the face of the washer to permit of its being drawn with a claw hammer. This effectually locks the nut. Wrought washers may be effectually locked by nicking the thread with a center punch after the nut has been screwed home.

Wrought washers, sometimes called punched, are also used to a considerable extent in this class of structures. They are circular in form, and are stamped out from sheet iron, with a hole punched through the center of them.

Table 51 gives the dimensions of wrought washers, and the number of each in a keg of 150 pounds:

TABLE 51.

Showing the Average Number of Wrought-Iron Washers in a Keg of 150 pounds of each Standard Size, as Adopted by the Association of Bolt and Nut Manufacturers of the United States.

Diameter.	Size of Hole.	Thickness, Wire Gauge.	Size of Bolt.	Number in 150 Pounds.
$\frac{1}{2}$	$\frac{1}{4}$	No. 18	$\frac{3}{16}$	80,000
$\frac{5}{8}$	$\frac{5}{16}$	No. 16	$\frac{1}{4}$	34,285
$\frac{3}{4}$	$\frac{5}{16}$	No. 16	$\frac{1}{4}$	22,000
$\frac{7}{8}$	$\frac{3}{8}$	No. 16	$\frac{5}{16}$	18,500
1	$\frac{7}{16}$	No. 14	$\frac{3}{8}$	10,550
$1\frac{1}{4}$	$\frac{1}{2}$	No. 14	$\frac{7}{16}$	7,500
$1\frac{3}{8}$	$\frac{9}{16}$	No. 12	$\frac{1}{2}$	4,500
$1\frac{1}{2}$	$\frac{5}{8}$	No. 12	$\frac{9}{16}$	3,850
$1\frac{3}{4}$	$\frac{11}{16}$	No. 10	$\frac{5}{8}$	2,500
2	$\frac{13}{16}$	No. 10	$\frac{3}{4}$	1,600
$2\frac{1}{4}$	$\frac{15}{16}$	No. 9	$\frac{7}{8}$	1,300
$2\frac{1}{2}$	$1\frac{1}{16}$	No. 9	1	950
$2\frac{3}{4}$	$1\frac{1}{4}$	No. 9	$1\frac{1}{8}$	700
3	$1\frac{3}{8}$	No. 9	$1\frac{1}{4}$	550
$3\frac{1}{2}$	$1\frac{1}{2}$	No. 9	$1\frac{3}{8}$	450

CONNECTION WITH EMBANKMENT—PROTECTION AGAINST ACCIDENTS.

1775. Connection with Embankment.—There are two methods, in general use, of connecting a trestle with an embankment, viz., by means of a bank crib, and by means of a bank bent. In the former method the crib is usually built of 12-in. by 12-in. square timbers *halved* one into the other and drift-bolted at each intersection of the timbers. There are several courses of timbers depending upon the height of the embankment. The building of the crib should be deferred until the rest of the trestle is completed, so as to allow all possible time for the settlement of the embankment. Before commencing the crib, a space of ample size to receive it should be excavated from the end of the embankment and the earth well rammed for a foundation before the timbers are put in place. The correct elevation for this foundation should be determined by the engineers, so that the top of the crib may have the proper elevation without hewing away any of the timber. The timbers composing the front of the crib, i. e., the part facing the trestle, should be at least 10 feet long, and those parallel to the track of equal length. The top of the crib should be fixed exactly at grade, so that trains may pass from the embankment to the trestle, and *vice versa*, without any jolting. Timbers frequently vary $\frac{1}{2}$ inch in thickness, so that the actual elevation of the top of the crib may vary 1 or 2 inches from the calculated one. This discrepancy may be readily remedied by shims, if the top of the crib is too low, and by notching down the stringer, if the top is too high. It is well to have the stringers extend back from the face of the crib several feet. The bottoms of the stringers should be kept from coming in contact with the earth of the embankment. This may be prevented by spiking planks to the crib timbers underneath the stringers. The stringers should be drift-bolted to the crib timbers. Such a connection between embankment

and trestle as we have just described is shown in Fig. 617.

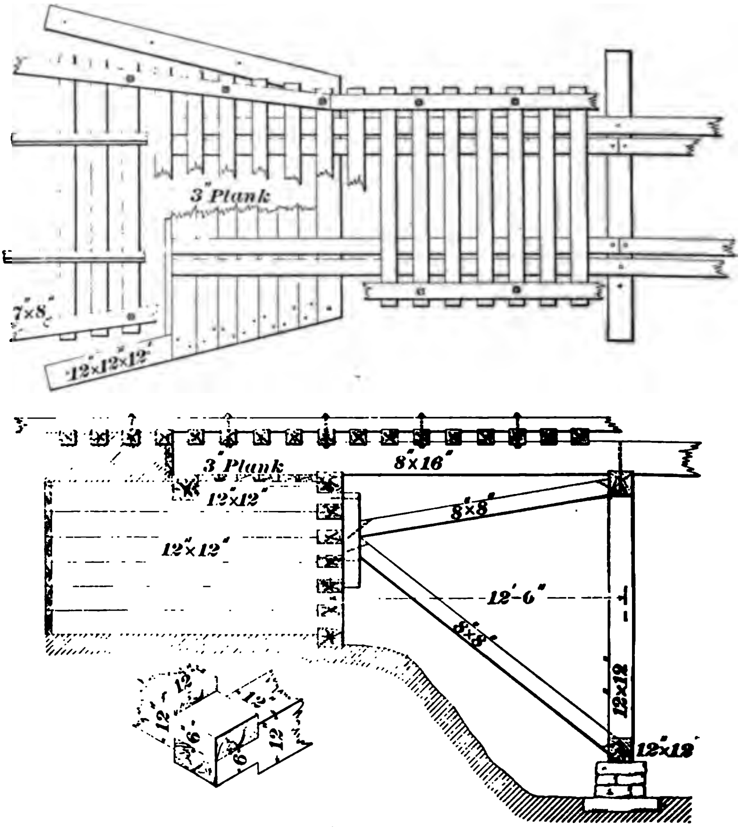


FIG. 617.

Connection between the embankment and the trestle may be made by means of a *bank* bent, either of piles or framed. This construction is more favored than the crib form previously described. It consists of a strong frame or pile bent built into the slope at the end of the embankment for the support of the stringers. If piles are used, the bent should contain four piles deeply driven into the embankment, so that they will not only safely carry the train load, but will sustain the pressure of the back filling, which is

carried up to the base of the stringers. To hold this piling in place, the back of the bent is close planked with 3-inch or 4-inch plank. When the bank bent is of considerable height, struts of 8-in. by 8-in. stuff should extend from the bank bent to the timbers of the first trestle bent, to insure its stability. When the bank bent is of framed timber, special pains should be taken to insure a safe founda-

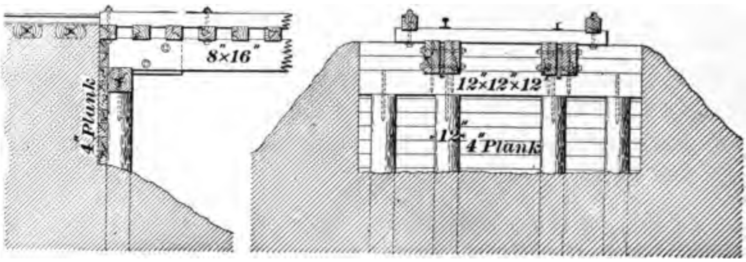


FIG. 618.

tion for the sill. Sub-sills of 12-in. by 12-in. timber, laid in trenches, form a good foundation. Before laying the sub-sills, the ground should be thoroughly rammed to ensure against settlement. This construction is illustrated in Fig. 618.

1776. Refuge Bays.—On all trestles of a length of 200 feet or more, refuge bays should be built where workmen or track walkers can find safety when overtaken by a train. They consist of small projecting platforms supported by ties which are given the additional length necessary to include the refuge bays. A refuge bay of approved pattern is shown in Fig. 619. On trestles of a length exceeding

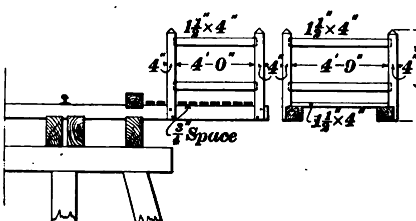


FIG. 619.

1,000 feet, every fourth refuge bay should be large enough to contain a hand car and section gang. While repairs are being made on a trestle, before work is commenced,

the hand car, together with all idle tools, should be placed in a refuge bay, and should remain there until the work is finished.

1777. Foot Walks.—On some roads it is customary to place between the rails a foot walk of inch boards from 1 to 2 feet in width. This is a mistake, in that it encourages the public to use a trestle as a thoroughfare on account of the ease in crossing it; it increases the danger of fire, as the walk forms a lodgment for coals dropped from the fire-boxes of the engines, and it tends to careless inspection on account of the difficulty of reaching the parts of the structure which are covered by the walk.

1778. Fire Protection.—Every trestle should be provided with the means of protection against fire. This is sometimes effected by covering the tops of ties and stringers with sheet iron. A simpler and more effective protection is afforded by water stored in tubs at intervals of not more than 200 feet, and provided either with buckets or large dippers. The buckets should be of metal, wood pulp, or paper. Metal well painted is preferable. The track walker should examine all tubs at least once each week and report their condition to the section foreman, whose business it is to keep them full of water. Kerosene barrels sawed in two make excellent tubs—cheap and enduring.

An equally important safeguard against fire is the cutting and burning of all grass and brush from the right of way adjacent to the trestle, and the removal and burning of all rubbish which could afford any lodgment for sparks. The grass and brush should be cut early in the season, when the stubble is too green to burn.

It is the contractor's business to protect the trestle against fire during construction by the removal and burning of all brush and rubbish which could in any way threaten its safety. A clause to this effect should have a place in every contract.

FIELD ENGINEERING AND ERECTING.

1779. Locating Bents.—The number of bents composing the trestle and the number of the station at the beginning and end of the same are determined from an inspection of the profile. The center line of the trestle is then run in, a plug being driven on the center line locating each bent. It is customary to place these center plugs 1 foot in advance of the bent centers so that they will not be disturbed while placing the bents in position. The center plugs being driven, the transit is set up at each plug and stakes set at right angles to the center line, giving the direction of the sill. These stakes are, like the center plug, 1 foot in advance of the required center line of the sill. In case the trestle is built on a curve, the bents should stand on radial lines.

It is of the first importance that the levels be correct, and to facilitate the checking of them, a bench mark with an elevation of about the grade of the rail should be established at the end of the trestle, and another near the lowest point of the line over which the trestle passes. At each center plug a strong stake should be driven, with the top of the stake at the level of the top of the foundation for that bent. One grade stake at each bent is sufficient, as the workmen can transfer that elevation to other points, if necessary, with an ordinary carpenter's or mason's level.

1780. Erecting.—Trestle bents of moderate height are framed, lying flat on the ground, with the sills so placed that when the bent is raised it will occupy its proper position. The raising is effected by means of blocks and a fall, the power being ordinarily applied by either horses or a gang of men. The end bent is first raised and braced in position, and the tackle for raising the next bent attached to it. Stay ropes should be attached to a bent before it is raised, to steady it and to prevent it from being pulled over after it has reached an upright position. As soon as a bent is raised, it should at once be fastened in position by means of **stay lath** nailed to it and the bent immediately

preceding. The sway-bracing should be fastened immediately, and when no longitudinal bracing is to be added, the stringers should be put in place and fastened before raising another bent.

High trestles, composed of several sections placed one above the other, and separated by purlins (see Fig. 627), are usually erected as follows: The bottom deck having been raised, the purlins are placed upon it, and a temporary floor laid on the purlins, upon which the bent forming the next section is placed and raised precisely as though it lay on the ground.

Special designs require special methods, but the plan generally adopted is that given above. A tack or nail is driven in each cap on the center line for the accurate placing of the stringers. After the ties and guard-rails are in place and fastened, tacks are driven in ties at intervals of about 50 feet, to guide the track layers.

1781. Preservation of Joints. — At every point where two pieces of timber come in contact, they should be painted with some preservative material. As trestle timbers are usually rough, a considerable quantity of material is necessary, if all joints are to be properly treated; white lead, though effective, is too expensive. Hot coal tar is a cheap and effective wood antiseptic, and available everywhere. Creosote oil is also much used, and when the finances of the company admit of it, a trestle built of timber which has been thoroughly treated with creosote oil under pressure is undoubted economy.

1782. Trestle Specifications.—There is no class of structures of the importance of wooden trestles upon which there has been so gross neglect in the matter of specifications. Many important contracts contain but a few lines, while others of equal importance carry specifications purely general in character, in which many points of the first importance are entirely neglected. The following specifications are general, but are sufficiently detailed to guide the student in making an application to a particular structure:

STANDARD SPECIFICATIONS FOR WOODEN TRESTLES.

CLEARING.

Before commencing work on any structure, the ground must be entirely cleared of logs, stumps, trees, and brush of every description. All combustible material must be piled at convenient places and completely burned. Trees outside the right of way which, by falling, may endanger the trestle, must be felled by the contractor, it being understood that permission to fell such trees shall be obtained by the railroad company from the land owner. Such portions of the right of way as shall be deemed necessary by the engineer shall be grubbed.

DRAWINGS.

The drawings are to the scale indicated and marked; but in all cases the figures are to be taken, and in case of omission the engineer in charge is to be referred to for dimensions. Under no circumstances are the drawings to be scaled either by the contractor or by any of his men. The engineer will be required to mark the dimensions upon the contractor's blue-print and to keep a record of the same in his office.

DIMENSIONS.

All posts, braces, clamps, stringers, packing-blocks, ties, guard-timbers, sills, and all timber generally, will be of the exact dimensions given and figured upon the plan. Variations from these will be allowed only upon the written consent of the engineer in charge.

TIMBER.

All timber shall be of good quality and of such kinds as the engineer shall direct, and be free from wind-shakes, black, loose, or unsound knots, worm holes, and all descriptions of decay. It must be sawed true and out of wind, and

full size. Under no circumstances will any timber cut from dead logs be allowed to be placed in any part of the structure; it must in every case be cut from living trees.

PILES.

Piles shall be cut from live, thrifty timber. They will be either round or square, as may be required by the engineer. Round piles must be straight, be stripped of all bark, and be well trimmed. They must be at least twelve (12) inches in diameter at the cut-off, when cut to grade to receive the cap. The smaller end must be at least eight (8) inches in diameter.

Square piles must be hewn (or sawed) twelve (12) inches square. They must have at least nine (9) inches of heart wood on each face from the head of the pile after being cut off to grade, to five (5) feet below the surface of the ground into which the pile is driven.

All piles must be properly pointed. They shall, if required, be shod with shoes of cast or wrought iron, made according to plans furnished by the engineer. In driving they shall be banded with wrought-iron rings of suitable weight to prevent splitting. The actual cost, delivered on the ground, of the necessary shoes and rings will be allowed to the contractor. Piles must be driven to hard bottom or until they do not sink more than five (5) inches under the last five (5) blows from a hammer of at least two thousand (2,000) pounds weight, falling free twenty-five (25) feet. All piles injured in driving, or driven out of place, shall be either withdrawn or cut off, as the engineer may elect, and others driven in their stead. The piles thus replaced will not be paid for. All piles under track stringers must be accurately spaced and driven vertically, and in each bent the batter piles will be driven at the angle shown.

Piles shall be measured by the lineal foot after they are driven and cut off, and the price per lineal foot shall be understood to cover the cost of transportation, removing the bark, driving, cutting off, and all labor and materials required in the performance of the work, but that portion of

each pile cut off shall be estimated and paid for by the lineal foot as "piles cut off."

The contractor must give all facilities in his power to aid the pile recorder in his duties.

Parts of pile heads projecting beyond the cap must be adzed off at an angle of 45°.

FRAMING.

All framing must be done to a close fit and in a thorough and workmanlike manner. No blocking or shimming of any kind will be allowed in making joints, nor will open joints be accepted.

All joints, ends of posts, piles, etc., and all surfaces of wood on wood shall be thoroughly painted with

*hot creosote oil and covered with a coat of thick asphaltum;
hot asphaltum;
hot common tar;
a good, thick coat of white lead ground and mixed with pure linseed oil.

All bolt and other holes bored in any part of the work must be thoroughly saturated with

*hot creosote oil;
hot asphaltum;
hot tar;
coal tar;
white lead mixed with pure linseed oil;
linseed oil.

And all bolts and drift bolts before being put in place must be

*warmed and coated with hot creosote oil;
warmed and coated with hot asphaltum;
warmed and coated with hot tar;
warmed and coated with hot coal tar;
coated with coal tar;
coated with white lead and linseed oil.

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* Optional methods of treatment.

fifty (550) pounds, suspended at the center of a bar one (1) inch square, and four and one-half ($4\frac{1}{2}$) feet between supports. They must be smooth, well shaped, free from air holes, cracks, cinders, and other imperfections.

All iron before leaving the shop must be thoroughly soaked in boiled linseed oil.

INSPECTION AND ACCEPTANCE.

All materials will be subject to the inspection and acceptance of the engineer before being used. The contractor must give all proper facilities for making such inspection thorough.

Any omission by the engineer to disapprove the work at the time of a monthly or any other estimate being made, shall not be construed as an acceptance of any defective work.

PROTECTION AGAINST FIRE.

The contractor must, each evening, before quitting work, remove all shavings, borings, and scraps of wood from the deck of the trestle and from proximity to the bents, and upon the completion of the work must take down and remove to a safe distance all staging used in the erection of the work, and remove and burn all fragments of timber, shavings, etc.

ROADS AND HIGHWAYS.

Commodious passing places for all public and private roads shall be maintained in good condition by the contractor, and he shall open and maintain thereafter a good and safe road for passage on horseback along the whole length of his work.

RUNNING OF TRAINS.

The contractor shall so conduct all his operations as not to impede the running of trains or the operation of the road. He will be responsible to the railroad company for

all injuries to rolling stock or damages from wrecks caused by his negligence. The cost of such damage will be retained from his monthly and final estimates.

RISKS.

The contractor shall assume all risks from floods, storms, and casualties of every description, except those caused by the railroad company, until the final estimate of the work.

LABOR AND MATERIAL.

The contractor must furnish all labor and material incidental to or in any way connected with the manufacture, transportation, erection, and maintenance of the structure until its final acceptance.

Disorderly, quarrelsome, or incompetent men in the employ of the contractor, or those who persist in doing bad work in disregard of these specifications, must be discharged by the contractor when requested to do so by the engineer.

Whenever the chief engineer may deem it advisable, he may name the rates and prices to be paid by the contractors, for such time as he may designate, to the several classes of laborers and mechanics in their employ, and for the hire of horses, mules, teams, etc., and these shall not be exceeded; and having given due notice to the contractors of his action in regard to these matters, they shall be bound to obey his orders in relation thereto. The chief engineer shall not, however, name a rate or price for any class of labor, etc., higher than the maximum rates being paid by the contractor paying the highest for that class.

INTOXICATING LIQUORS.

Contractors will not themselves, nor by their agents, give or sell any intoxicating liquors to their workmen or to any persons at or near the line of the railway, nor allow any to be brought on the works by the laborers or any other person, and will do all in their power to prevent their use in the vicinity of the work by persons in their employ. A

continued disregard for this clause will, if deemed necessary by the engineer, be considered as a good and sufficient reason for declaring the contract forfeited.

DAMAGES AND TRESPASS.

Contractors shall be liable for all damages to landholders, arising from loss of or injury to crops or cattle, sustained by any cause or thing connected with the works or through any of their agents or workmen. They will not allow any person in their employ to trespass upon the premises of persons in the vicinity of the works, and will forthwith, at the request of the engineer, discharge from their employ any person that may be guilty of committing damage in this respect. They will also maintain any fences that may be necessary for the proper protection of any property or crops.

REMOVAL OF DEFECTIVE WORK.

The contractor will remove at his own expense any material disapproved by the engineer, and will remove and rebuild, without extra charge, and within such time as may be fixed by the engineer, any work appearing to the engineer, during the progress of the work or after the completion, to be unsound, or improperly executed, notwithstanding that any certificate may have been issued as due for the execution of the same. The engineer shall, however, give notice of defective work to the contractor as soon as he shall have become cognizant of the same. On default of the contractor to replace the work as directed by the engineer, such work may be done by the railroad company at the contractor's expense.

DELAYS.

No charge shall be made by the contractor for hindrances and delay, from any cause, in the progress of the work; but it may entitle him to an extension of the time allowed for completing the work, sufficient to compensate

for the detention, to be determined by the engineer, provided he shall give the engineer in charge immediate notice, in writing, of the detention.

EXTRA WORK.

No claim shall be allowed for extra work, unless done in pursuance of a written order from the engineer, and unless the claim is made at the first estimate after the work is executed. The chief engineer may, at his discretion, allow any claim, or such part of it as he may deem just and equitable.

Unless a price is specified in the contract for the class of work performed, extra work will be paid for at the actual cost of the material remaining in the structure after its completion and the cost of the labor for executing the work plus fifteen (15) per cent. of the total cost. This fifteen (15) per cent. will be understood to include the use and cost of all tools and temporary structures, staging, etc., and the contractor's profit, and no extra allowance over and above this will be made.

INFORMATION AND FORCE ACCOUNTS.

The contractor will aid the engineer in every way possible in obtaining information, and freely furnish any which he may possess, by access to his books and accounts, in regard to the cost of work, labor, time, material, force account, and such other items as the engineer may require for the proper execution of his work, and shall make such reports to him from time to time as he may deem necessary and expedient.

PROSECUTION OF THE WORK.

The contractor shall commence his work at such points as the engineer may direct, and shall conform to his directions as to the order of time in which the different parts of the work shall be done, as well as the force required to complete the work at the time specified in the contract. In case the contractor shall refuse or neglect to obey the orders of the engineer in the above respects, then the engineer shall have

the power to either declare the contract null and void and relet the work, or to hire such force and buy such tools at the contractor's expense as may be necessary for the proper conduct of the work, as may, in his judgment be for the best interests of the railroad company.

CHANGES.

At any time during the execution or before the commencement of the work, the engineer shall be at liberty to make such changes as he may deem necessary, whether the quantities are increased or diminished by such changes, and the contractor shall not be entitled to any claim on account of such changes beyond the actual amount of work done according to these specifications at the prices stipulated in the contract, unless such work is made more expensive to him, when such rates as may be deemed just and equitable by the chief engineer will be allowed him; if, on the other hand, the work is made less expensive, a corresponding deduction may be made.

QUANTITIES.

It is distinctly understood that the quantities of work estimated are approximate, and the railroad company reserves the right of having built only such kinds and quantities, and according to such plans, as the nature or economy of the work may, in the opinion of the engineer, require.

ENGINEER.

The term **engineer** will be understood to mean the chief engineer, or any of his authorized assistants or inspectors, and all directions given by them, under his authority, shall be fully and implicitly followed, carried out, and obeyed by the contractor and his agents and employes.

PRICE AND PAYMENT.

The prices bid will include the furnishing of materials, tools, scaffolding, watching, and all other items of expense in any way connected with the execution and maintenance

of the work until it is finally accepted and received as completed. The contractor will be paid only for the piles, timber, and iron left in the structure after completion. No wastage in any kind of material will be paid for except in the case of piles, when the "piles cut off," which can not be used on any other part of the contractor's work, will be paid for at the rate agreed upon. After the material cut off is paid for, it is to be considered the property of the railroad company, and is to be neither removed nor used by the contractor without the consent of the engineer, and then only upon the repayment of the price which has been paid for it.

The piles and "piles cut off" will be paid for by the lineal foot, the former driven in place.

The timber and lumber remaining in and necessary to the completed structure will be paid for by the thousand feet, board measure.

The iron will be paid for by the pound, and only that remaining in the structure after its completion.

The masonry for foundations will be paid for by the cubic yard.

The excavations for foundations will be paid for by the cubic yard.

The retained percentage will not be paid on the cost of any single structure until the *final estimate* is due on the entire work embraced in the contract.

When the trestling and grading are let under one contract, or when a general contract, as *by the mile*, includes a considerable portion or all of a line, many of the preceding clauses will be omitted in the section of the contract pertaining to trestles, as they are general requirements applicable to all classes of work embraced by the contract. Special conditions obtaining in a particular section of the country may also require modifications of some of the given clauses. The specifications given are general and are intended to meet all certain requirements and secure justice to both the contractor and the railroad company.

BILLS OF MATERIAL, RECORDS, AND MAINTENANCE.

1783. Proper Forms.—Proper forms of bills of material are of great importance to both contractor and engineer: to the former in ordering and placing material, and to the latter in checking, estimating, and keeping records of the same. Few young engineers have any knowledge of such forms, and many engineers of experience have been content with slovenly cut-and-try methods. The following is a proper form of bill of material:

TRESTLE NO. 2.

DIVISION NO. 4. ______ RESIDENCY NO. 3.

BILL OF IRON.

No. of Pieces.	Name.	Use.	Size.	Weight.
		WROUGHT IRON.		
24	Drift-bolts	Stringers to bank sills	$\frac{3}{4}''$ sq. $\times 24''$	
26	Drift-bolts	Stringers to caps....	$\frac{3}{4}''$ sq. $\times 24''$	
6	Drift-bolts	Sills to mud-sills....	$\frac{3}{4}''$ sq. $\times 20''$	
102	Boat spikes	Ties to stringers	$\frac{1}{2}'' \times 12''$	
150	Boat spikes	Guard-rails to ties...	$\frac{1}{2}'' \times 12''$	
26	Bolts......	Guard-rails to jack-stringers	$\frac{3}{4}'' \times 31\frac{1}{2}''$	
12	Bolts......	Caps to posts	$\frac{3}{4}'' \times 22''$	
16	Bolts......	Sway-bracing.......	$\frac{3}{4}'' \times 20''$	
32	Bolts......	Packing for stringers	$\frac{3}{4}'' \times 22''$	
	Total			
		CAST IRON.		
172	Washers...	Under heads and nuts of bolts.........	$1'' \times 3''$	
32	Separators	Between stringers...	$2'' \times 3''$	
	Total			

All bills of material should be copied in a letter book. In making out bills of material, the contractor should be allowed the full length of each stick, including the tenon,

BILL OF TIMBER.

Number of Bent.	Number of Pieces.	Name.	Size.	Feet, B. M.	Total Feet, B. M.
1	Height, 9 feet.				
	2	Cap	6″ × 12″ × 14′ 0″	168	
	2	Plumb posts	12″ × 12″ × 8′ 0″	192	
	2	Batter posts	12″ × 12″ × 9′ 0″	216	
	1	Sill	12″ × 12″ × 12′ 4″	148	
	8	Blocks—Mud-sills	12″ × 12″ × 2′ 6″	240	964
2	Height, 13 feet.				
	2	Cap	6″ × 12″ × 14′ 0″	168	
	2	Plumb posts	12″ × 12″ × 12′ 0″	288	
	2	Batter posts	12″ × 12″ × 13′ 2″	316	
	1	Sill	12″ × 12″ × 14′ 2″	170	
	2	Sway-braces	3″ × 10″ × 16′ 6″	83	
	8	Blocks—Mud-sills	12″ × 12″ × 2′ 6″	240	1,265
3	Height, 10 feet.				
	2	Cap	6″ × 12″ × 14′ 0″	168	
	2	Plumb posts	12″ × 12″ × 9′ 0″	216	
	2	Batter posts	12″ × 12″ × 10′ 1″	242	
	1	Sill	12″ × 12″ × 12′ 8″	152	
	2	Sway-braces	3″ × 10″ × 14′ 0″	70	
	8	Blocks—Mud-sills	12″ × 12″ × 2′ 6″	240	1,088
	Floor System	and Miscellaneous Parts.			
	8	Bank sills	12″ × 12″ × 12′ 0″	1,152	
	10	Stringers and jack-stringers	8″ × 16″ × 25′ 0″	2,667	
	4	Stringers	8″ × 16″ × 12′ 6″	534	
	51	Ties	6″ × 8″ × 12′ 0″	2,448	
	9	Guard-rails	6″ × 8″ × 20′ 0″	720	7,521
	Grand total,				10,838

and where the tenon is cut on a skew, as in batter posts, etc., the full size for the extreme length of stick should be reckoned.

1784. The number of feet B. M. (board measure) in a stick of timber or in lumber 1 inch or over in thickness is found by the following rule:

Multiply together the breadth and thickness in inches and the length of the stick in feet, and divide the product by 12. The quotient will be the number of feet required.

If we denote the breadth by b, the thickness by t, and the length by L, we may put the question in algebraic form as follows:

$$Feet\ B.\ M. = \frac{b \times t \times L}{12}. \qquad \textbf{(126.)}$$

When lumber is less than 1 inch in thickness, it is always reckoned as though it were a full inch thick.

A table like the following, containing the number of feet B. M. in each piece entering into the standard trestle will greatly facilitate the making out of bills of material:

General.—Each trestle will require:

8 Bank sills, 12″ × 12″ × 12′ 0″..............	1,152 ft., B. M.
4 Dump boards, 4″ × 8″ × 11′ 4″......... ...	121 ft., B. M.
Stringer pieces, 8″ × 16″ × 25′ 0″ contain each	267 ft., B. M.
Ties, 6″ × 8″ × 12′ 0″ contain each..........	48 ft., B. M.
Guard-rails, 6″ × 8″ × 20′ 0″ contain each....	80 ft., B. M.

1785. Inspection.—After the road is completed and turned over to the operating and maintenance departments, the trestles, as well as all other structures forming a part of the roadway, should be regularly and thoroughly inspected. At least once every year, at a favorable season, the work of inspection should be performed by the engineer in charge of the maintenance-of-way department. The inspection should be thorough in every detail, and where the traffic is heavy, this inspection should be made twice a year.

Once each month all structures should receive a careful examination by a competent inspector. Not only the deck timbers, but all timbers entering into the structure, should be examined, and every necessary help should be afforded

the inspector to facilitate his work. He should make out a complete report on proper blanks of the condition of each structure, forwarding them to either the division engineer or division superintendent, who, having examined and approved the reports, forwards them to the engineer of maintenance of way.

A further inspection should be made by the *track walker*, and that as often as he crosses the bridge or trestle, though it be several times a day. Of course, the inspection of the latter will consist only of a general oversight, but sufficient to detect at once any exterior defect or lack. The track walker will be provided with blanks for making out reports. The following form is suitable for his report:

BLACK RIVER VALLEY RAILROAD.

TRACK WALKER'S DAILY REPORT ON THE CONDITION OF BRIDGES AND TRESTLES.

Number of Bridge.	Time.		Condition.	
	A. M.	P. M.	A. M.	P. M.
M. P. 123 *A*	7:45	5:45	X	X
M. P. 123 *B*	8:10	5:20	X	X
M. P. 124 *A*	8:30	4:50	X	X
M. P. 124 *B*	9:00	4:20	X	X
M. P. 124 *C*	9:50	3:50	X	X
M. P. 125 *A*	10:30	3:30	X	X
M. P. 125 *B*	10:50	3:00	X	X
M. P. 126 *A*	11:20	2:30	X	X
M. P. 126 *B*	11:45	1:40	X	X
M. P. 126 *C*	12:00	1:10	X	X

.... *Track Walker.*

.... *189*..........

These blanks are bound in pads of fifty sheets and carry a pasteboard cover for protection. When filled out the report is folded and endorsed on the back:

BLACK RIVER VALLEY RAILROAD.

Track Walker's Daily Report.

*Bridges and Trestles from *M. P. 123 A to M. P. 126 C.*

In the report, **X** in the column headed Condition, means "all right;" **O** means "injured or unsafe," by fire, washout, or from other cause. In case of danger, the fact must be reported by *telegraph* from the nearest station to the inspector of bridges, the division engineer, and the division superintendent.

1786. Inspector's Tools and Their Use.—An ax or hatchet and small auger are the essential part of an inspector's outfit. Decay generally commences at the surface of timber, and is at once manifest. On the other hand, dry rot, or *powder post*, as it is vulgarly termed, commences beneath the surface, and it frequently happens that a piece of timber, which from the surface appears perfectly sound, is totally decayed inside, leaving only a shell of sound timber. Where this form of decay is in an advanced stage, it may be detected by striking a few blows upon the surface of the timber, which will give a hollow sound; but where the shell is thick, the defect may be revealed by boring a small hole into the timber, the degree of ease with which the hole is bored determining the degree of soundness of the timber. The simplest, and an excellent way as well, of testing timber is by driving a slim wire nail or spike into the wood; the soundness of the timber in this case, as in boring, will be revealed by the ease or difficulty in driving the nail. Whenever a hole is bored, it should be plugged as soon as it has served its purpose, and but few holes should be bored in the same stick.

Piles in trestles need not be examined for decay until they have been several years in the ground; but whenever there is any suspicion of decay, an examination should be made at once. Decay first attacks the piles at or near the surface of the ground, and, in order to examine them, the earth must be removed to the depth of 1 foot, or more if necessary. A short, sharp-pointed steel bar is a good tool for testing the

* Mile post.

soundness of piles. After a pile has been examined, the cavity made for the examination should be refilled and the earth well tamped.

In every case where a serious defect is discovered, which in any way threatens the safety of the structure, the inspector should at once notify, *by telegraph* from the nearest station, the division engineer and division superintendent of the fact, stating as briefly and clearly as possible the nature and extent of the defect or damage.

1787. Bridge Numbers.—On most roads the bridges and trestles are numbered consecutively, beginning at the terminus of the road. A much better way, now being introduced, is to number the bridges alphabetically, commencing at each mile post (M. P.). Thus, bridge No. 96 A means the first bridge after passing mile post 96, and at once conveys to the mind a definite idea of location. On the other hand, bridge No. 125, unless some other explanatory reference is given, is of small aid in locating a bridge. Bridge numbers are usually painted in black figures three inches in height on a white ground. A 1¼-inch pine board of suitable width is given four or five coats of white lead, and the numbers painted upon it in heavy distinct lines. The boards should be of uniform height, and uniformly placed. The first right-hand cap of a trestle and the first right-hand tie of an open culvert on passageway are suitable locations for bridge numbers. Suitable forms of bridge numbers are shown in Figs. 620 and 621.

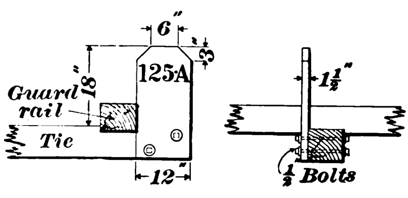


FIG. 620.

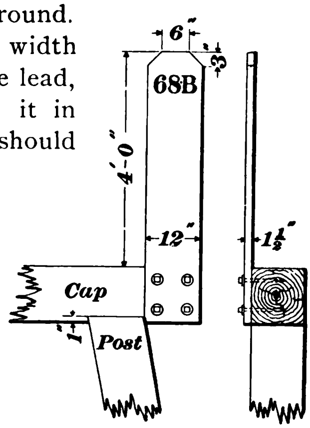


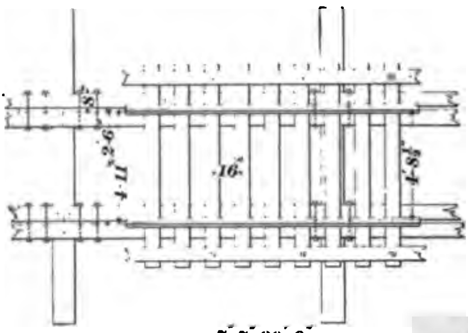
FIG. 621.

STANDARD TRESTLE PLANS.

1788. In this section, the purpose is to illustrate by complete plans the various types of trestles in general use, whose efficiency has been proved by long service.

STANDARD SINGLE-TRACK PILE TRESTLE.

1789. In Fig. 622 is given a plan of a pile trestle suitable for heights of from 6 to 20 feet. On roads with only a moderate traffic, bents of three piles each may be safely used for heights of from 6 to 10 feet, but for all through lines no trestle bent should contain less than four piles, having at the cut-off point a diameter of not less than 12 inches, inside of bark measurement.



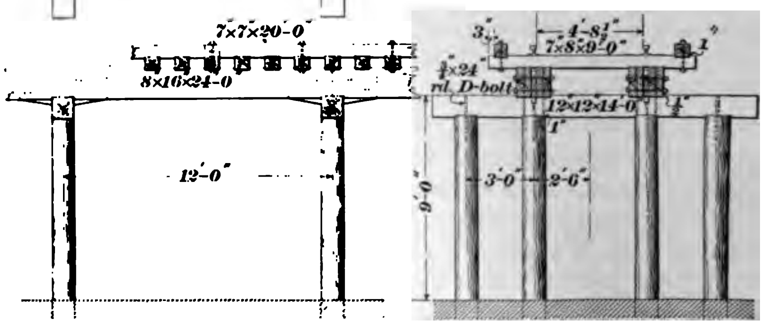


FIG. 622

It is customary to notch down the caps 1 inch on the pile heads. The main object for this notching is to hold the piles in place while they are being drift-bolted, in case they have been sprung in driving. The caps are drift-bolted to the piles with ¾ in. diam. × 24 in. drift-bolts, and the stringers to the caps with drift-bolts of the same dimensions. The ties are not fastened to the stringers, but notched down

1 inch over the stringers, which prevents any lateral movement. The guard-rails are so close to the rails that in case of derailment the weight of the derailed engine or car will bear almost directly upon the stringer. This form of trestle is simple and thoroughly efficient.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 7 in. × 7 in. × 20 ft., notched 1 in. over ties.
Ties, 7 in. × 8 in. × 9 ft., notched 1 in. over stringers.
Stringers, 8 in. × 16 in. × 24 ft., sized over caps to 15 in.
Packing-blocks, 2 in. × 16 in. × 4 ft., notched 3 in. over caps.

Bents: Caps, 12 in. × 12 in. × 14 ft., notched 1 in. over pile heads.
Piles, at least 12 in. in diameter at cut-off.

DIMENSIONS OF IRON DETAILS.

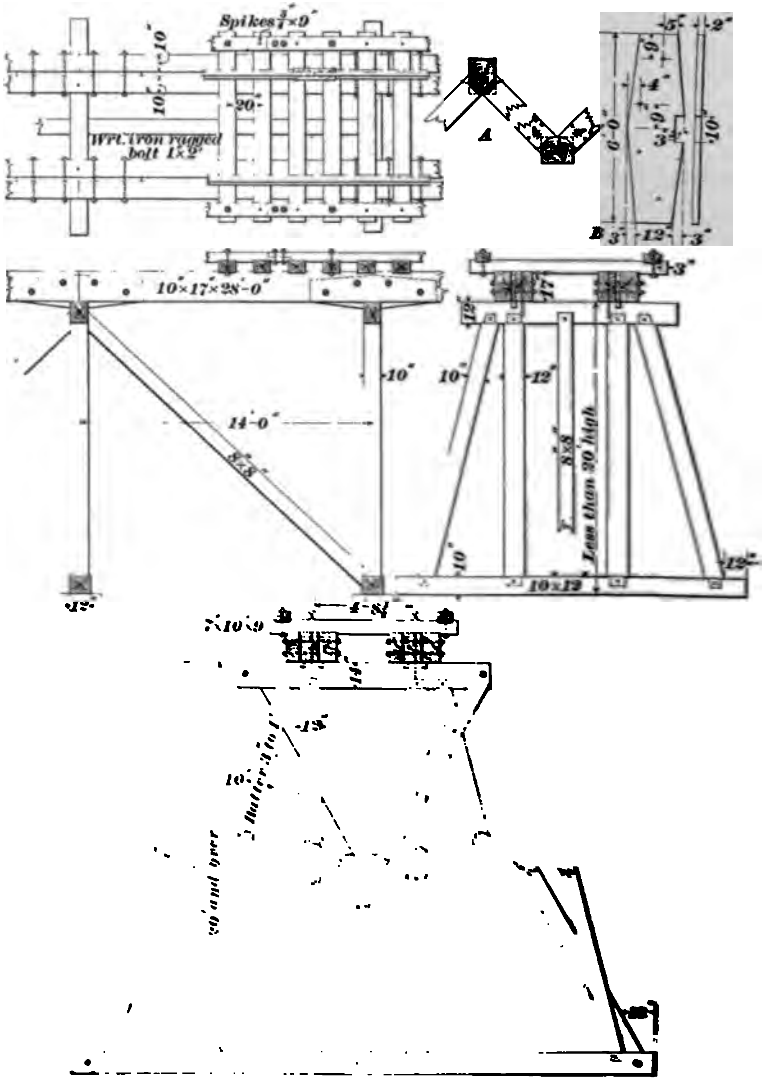
Bolts: $\frac{1}{2}$ in. × $15\frac{1}{2}$ in., guard-rails to ties.
$\frac{3}{4}$ in. × $20\frac{1}{2}$ in., through stringers at packing-blocks.

Drift-bolts, $\frac{3}{4}$ in. diam. × 24 in., stringers to caps and caps to piles.

STANDARD FRAMED TRESTLE, PENNSYLVANIA RAILROAD.

1790. The standard single-track framed trestle, as employed by the Pennsylvania Railroad, is shown in Fig. 623. Like all standard structures in use on this important line, this trestle is a model structure, combining great strength and simplicity of design. Its characteristic features are in the arrangement of the posts, by which the weight of the load is about equally divided between the vertical and the batter posts, and in the longitudinal bracing, shown in detail at *A*. It will be observed that only in trestles exceeding a height of 20 feet are the posts given dimensions so large as 12 in. × 12 in. in cross-section, and then only in the vertical posts. On the other hand, the stringer dimensions which are commonly adopted on other lines are considerably exceeded in this trestle. For spans

of 14 feet, two stringer pieces are required, each 10 in. × 17



... each 8 in. × 17 in.
... where it is most

likely to be needed. Many trestles are weak in the stringers, especially those designed for light traffic. On account of traffic interchange, these trestles are continually required to carry loads for which they were not designed, and often far beyond the point of safety. Numerous accidents have occurred directly attributable to this cause. In designing a trestle, due regard must be paid to this point. A little extra timber in the stringers will not add greatly to the cost of the structure, and will vastly increase its efficiency and the reputation of the road.

Special attention is called to the ties, which are much above the average in size of cross-section, though proportionately below the average in length. The same is true in the length of caps, which in trestles below 20 feet in height are only 10 feet in length, and in those of greater height only 12 feet in length, whereas 14 feet is the length generally adopted. This is unquestionably saving timber to good purpose. It is a mistake to space the guard-rail more than 15 inches from the track rail, and 12 inches is amply sufficient. The purpose of the guard-rail is to keep the derailed engine or car upon the trestle, and the less the space between the rail and the guard-timber, the less will be the danger of the ties being broken off by sudden shock and weight brought upon them. Where a wide space is left between the rail and the guard timber, a jack-stringer is indispensable, but it would seem a better policy to put the extra timber forming the jack-stringers into the track stringers, and with the extra length of tie make a shorter tie with larger cross-section. Batter posts have a batter of 3 inches to the foot. Mortises and tenons for the smaller posts are 3 in. × 5 in. × 7 in., and for the larger posts 3 in. × 5 in. × 8 in.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 5 in. × 8 in., notched 1 in. over ties.

Ties, 7 in. × 10 in. × 9 ft., notched ½ in. to receive guard-rails, and ½ in. over stringers.

Stringers:

Clear Span.	Number of Pieces Under Each Rail.	Width of Each Piece.	Depth of Stringers.
10	2	8 in.	15 in.
12	2	8 in.	16 in.
14	2	10 in.	17 in.
16	3	8 in.	17 in.

Packing-blocks, 2 in. × 18 in. × 6 ft.

Bents under 20 ft.: Cap, 10 in. × 12 in. × 10 ft.
Plumb posts, 10 in. × 12 in.
Batter posts, 10 in. × 10 in.; batter 3 in. to 1 ft.
Sill, 10 in. × 12 in.

Bents 20 ft. and over: Cap, 12 in. × 14 in. × 12 ft.
Plumb posts, 12 in. × 12 in.
Batter posts, 10 in. × 12 in.; batter 3 in. to 1 ft.
Sill, 12 in. × 12 in.
Sway-bracing, 3 in. × 10 in.

Bracing: Longitudinal, 8 in. × 8 in.

Treenails: Locust, 1 in. in diameter.

DIMENSIONS OF IRON DETAILS.

Bolts: ¾ in. × ——; guard-rails to ties.
¾ in. × ——; guard-rail joints.
¾ in. × ——; stringer joints; packing-blocks.
¾ in. × ——; sway-bracing to caps and sills;
3 in. wrought-iron washers used.

Drift-bolts (ragged): 1 in. × 24 in.; stringers to caps.

Spikes: Boat, ¾ in. × 9 in.; guard-rails to ties.
½ in. × 8 in.; sway-braces to posts.
Cut, —— × ——; longitudinal braces to caps and sills.

Wrought-iron washers: 2½ in. square for ¾-in. bolt.
3 in. round for ¾-in. bolt.

STANDARD FRAMED TRESTLE, CLEVELAND AND CANTON RAILROAD.

1791. A style of trestle which is aptly called a **compound timber trestle,** and growing much in favor, is illustrated in Fig. 624. The characteristic feature of this type is that the main members, such as stringers, caps, posts, sills, etc., are composed of two or more pieces bolted together. The principal advantages of this style of construction are in the reduction of the cost of timber and in the

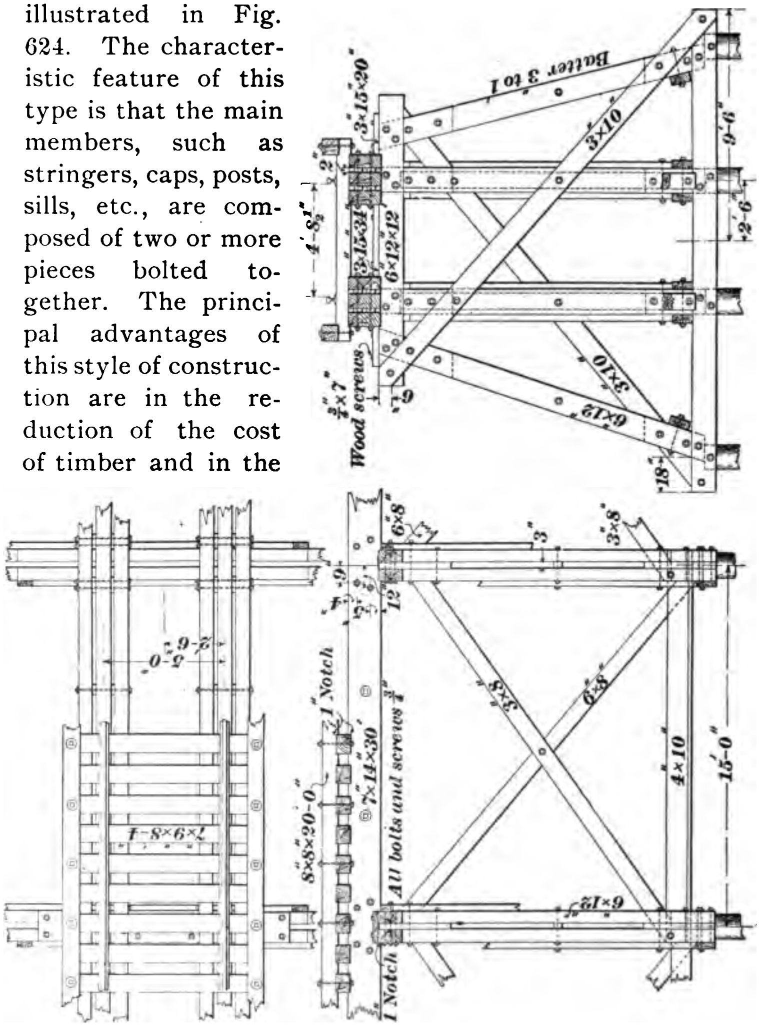


FIG. 624.

facility and safety with which repairs can be made. As the parts are bolted together, a defective piece may be

readily replaced, and that without endangering or delaying traffic. In general, a better quality of timber may be had in small dimensions than in large ones, and at much less cost. As the pieces forming each member are separated from each other, there is a complete circulation of air throughout the structure, which seasons and preserves the timber.

The amount of iron in the structure is necessarily large, but if it is well dipped in tar or asphaltum before being placed in the structure, the iron should outlast two or three wooden structures. This form of trestle is no more expensive to build than a framed structure, and its popularity is ample evidence of its general excellence.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 8 in. × 8 in., notched 1 in. over ties.
Ties, 7 in. × 9 in. × 8 ft. 4 in., notched 1 in. over stringers.
Stringers, 7 in. × 14 in. × 30 ft., notched 1 in. over caps.
Brace blocks, $\begin{cases} 3 \text{ in.} \times 15 \text{ in.} \times 20 \text{ in.} \\ 3 \text{ in.} \times 15 \text{ in.} \times 34 \text{ in.} \end{cases}$

Bents: Caps, 6 in. × 12 in. × 12 ft.
All posts, 6 in. × 12 in.
Sills, 6 in. × 12 in.
Sway-braces, 3 in. × 10 in.
Tenon blocks, 3 in. × 12 in. × 3 ft.

Longitudinal Braces: Girts, 4 in. × 10 in. × 17 ft.
Diagonals, $\begin{cases} 6 \text{ in.} \times 8 \text{ in.} \\ 3 \text{ in.} \times 8 \text{ in.} \end{cases}$

DIMENSIONS OF IRON DETAILS.

Bolts: ¾ in. × 14 in.; guard-rails to ties.
¾ in. × 26 in.; stringer joints; packing-bolts.
¾ in. × 21 in.; sway-braces to posts and at intersection of diagonal longitudinal braces.
¾ in. × 23 in.; longitudinal girts to plumb posts.
¾ in. × 19 in.; longitudinal girts to batter posts.
¾ in. × 18 in.; packing-bolts for posts.
¾ in. × 26 in.; interior diagonal braces to posts.

Washers: $\begin{cases} \frac{3}{4} \text{ in.} \times 3 \text{ in.} \\ 1 \text{ in.} \times 3\frac{1}{2} \text{ in.} \end{cases}$

Separators: 2 in. × $3\frac{1}{2}$ in.

STANDARD FRAMED TRESTLE, OHIO CONNECTING RAILWAY.

1792. In Fig. 625 we have the standard framed trestle adopted by the Ohio Connecting Railway. For heights under 30 feet, the bent consists of one deck, but for heights

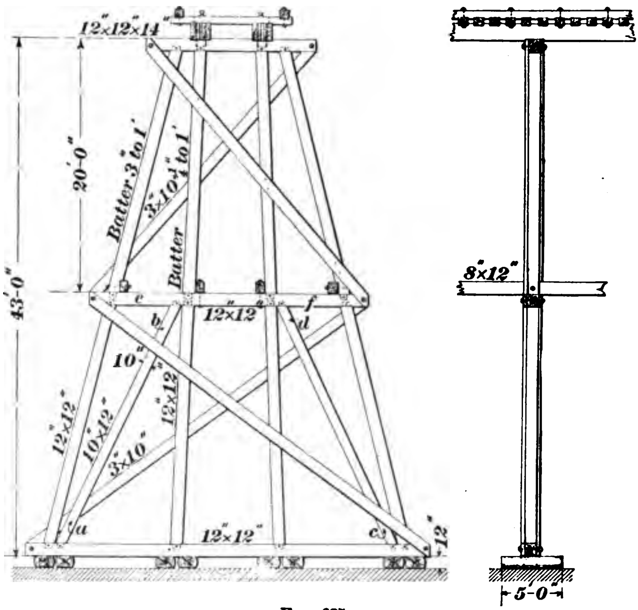


FIG. 625.

above 30 feet two decks are employed, as shown in the figure. As the middle posts are directly under the rails, they carry a large share of the load, and to distribute this load the counter posts *a b* and *c d* are employed. The inner posts are given a batter of $\frac{1}{4}$ inch to the foot, which helps to distribute the load. The sub-sills are inexpensive, fairly enduring, and easily renewed. The foundations should be of masonry if the trestle is to be permanent, and if the situation does not admit of masonry, piles should be used.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 8 in. × 8 in. × 20 ft., notched 1 in. over ties
Ties, 7 in. × 8 in. × 10 ft., notched 1 in. over stringers.
Stringers, 9 in. × 16 in. × 28 ft., notched 1 in. over caps.

Bents: Caps, 12 in. × 12 in. × 14 ft.
Posts, 12 in. × 12 in.
Counter posts, 10 in. × 12 in.
Sills, 12 in. × 12 in.
Sway-braces, 3 in. × 10 in.

Longitudinal Braces: Girts, 8 in. × 12 in.

DIMENSIONS OF IRON DETAILS.

Bolts: $\frac{3}{4}$ in. × $16\frac{1}{4}$ in.; guard-rails to ties.
$\frac{3}{4}$ in. × $20\frac{1}{2}$ in. }
$\frac{3}{4}$ in. × $17\frac{1}{2}$ in. } sway-braces to caps and sills.
$\frac{3}{4}$ in. × $22\frac{1}{2}$ in.; purlins to posts.
$\frac{3}{4}$ in. × 23 in.; stringers to caps.

Washers: $\frac{3}{4}$ in. × 3 in.

STANDARD DOUBLE-TRACK PILE TRESTLE, BOSTON AND ALBANY RAILROAD.

1793. A **double-track trestle** is nothing more than two single-track trestles so combined as to form one structure. In Fig. 626, we have the standard double-track pile trestle as adopted by the Boston and Albany Railroad. The two special features of this trestle to which the attention of the student is called are the use of split caps, shown in detail at *A*, and the lateral bracing more distinctly shown in the plan. The split caps, being but half the size of ordinary caps, may be had in better timber at less cost, and may be renewed without in any way interfering with traffic. The smaller-sized timbers, on account of their thorough and rapid seasoning, are less liable to suffer from dry rot, and being of comparatively small weight, they are easily and cheaply handled. It is a common practice, where split caps are used, to make the tenons at the end of the pile 6 inches in thickness. So great a thickness is unnecessary, and where

the piles are under 14 inches in thickness the shoulder left for the cap to rest upon is entirely too small. A tenon 3

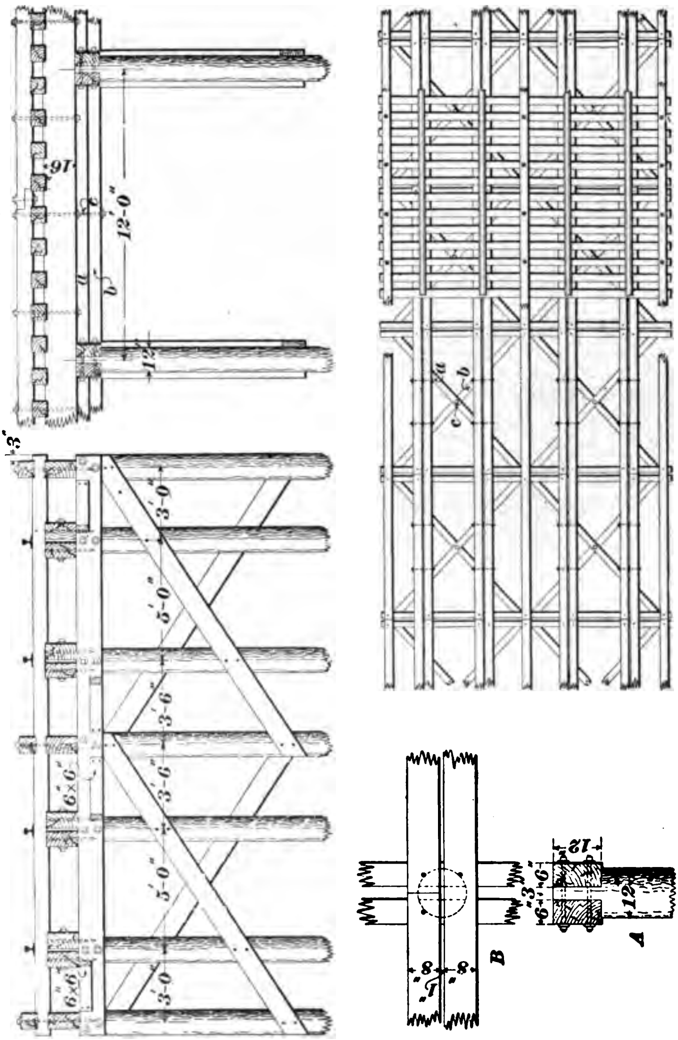


FIG. 626.

inches in thickness is ample and insures a shoulder of ample width. The stringer joint is shown in detail at *B*. The stringers are not notched over the caps, but are sized with

an adz to a uniform thickness. Large timbers are certain to vary from $\frac{1}{8}$ inch to $\frac{1}{4}$ inch in thickness; hence, the necessity of sizing. The notching of the stringers would prevent the removal of a cap unless the stringer was raised for the purpose.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 8 in. × 8 in., notched 1 in. over ties.
Ties, 7 in. × 8 in., notched 1 in. over stringers.
Stringers, 8 in. × 16 in. × 24 ft.

Bents: Caps, 6 in. × 12 in. × 24 ft.
Sway-braces, 3 in. × 10 in.
Piles, 12 in. in diameter.

Lateral Braces: 6 in. × 6 in.

DIMENSIONS OF IRON DETAILS.

Bolts: $\frac{1}{2}$ in. × 10 in.; splicing guard-rails.
$\frac{3}{4}$ in. × 32 in.; guard-rails to ties and stringers.
$\frac{3}{4}$ in. × 20 in.; through stringers at separators.
$\frac{3}{4}$ in. × 18 in.; caps to piles.
$\frac{1}{2}$ in. × 14 in.; at intersections of lateral braces.

Drift-bolts: $\frac{3}{4}$ in. × 24 in.; stringers to caps.

STANDARD FRAME TRESTLE, OREGON AND WASHINGTON RAILROAD.

1794. High trestles furnish opportunity for constructive skill and judgment of a high order. Methods of constructing trestles of this class, as of others, have changed much in recent years. More iron is introduced and less framing. Posts and sills are fastened together with dowels instead of with mortise and tenon; braces are fastened with bolts, and, wherever possible, the cutting of timber incident to framing is avoided. The braces are increased in size and reduced in number. Instead of short braces framed into the posts at each angle, long braces, reaching from one-half to the total width of the bent, are bolted to the main timbers. By this means, the strains due either to the wind pressure or the train load are distributed throughout the structure.

The trestle shown in Fig. 627 is a copy of one built on the line of the Oregon and Washington Railroad. Its height from ground to rail is about 100 feet, and for simplicity and

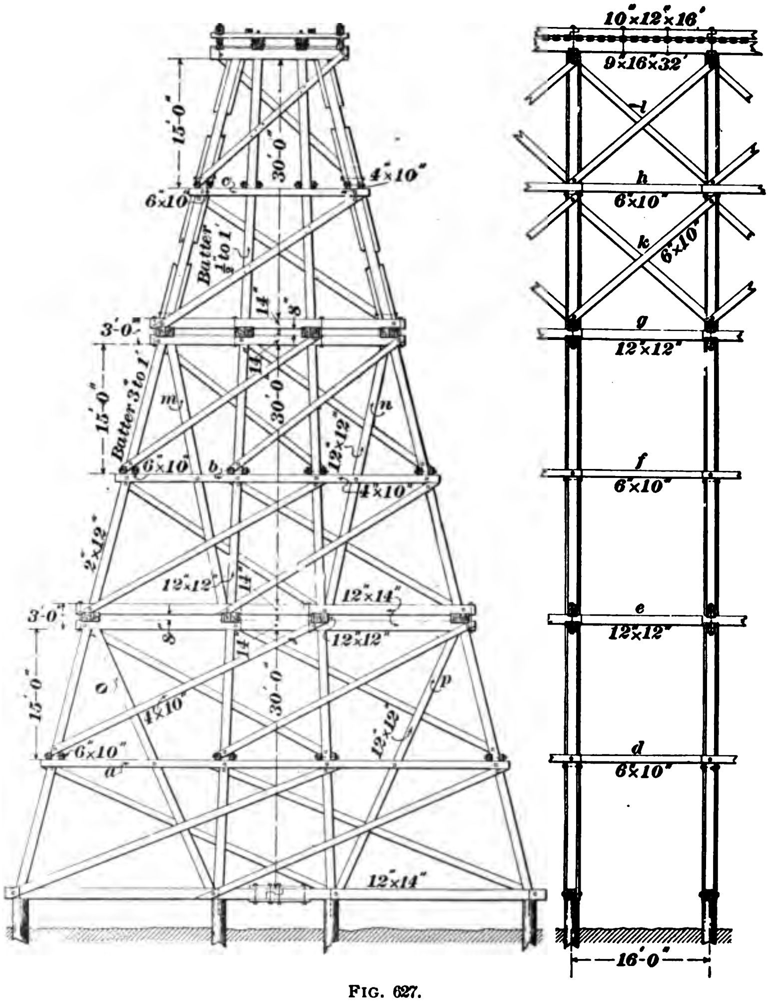


FIG. 627.

strength of design it has no superior. By battering the inside posts, the load is well distributed over the base, which has sufficient breadth to insure stability. The system of

sway-bracing is exceptionally good. The horizontal wales *a*, *b*, and *c*, which are bolted to the posts, practically double the number of decks and reduce the post lengths to one-half their actual length. They also form seats for the purlins *d*, *f*, and *h*.

Each bent consists of three sections of equal height, separated by eight 12 in. × 12 in. purlins, *c*, *g*. These purlins extend longitudinally the length of two bents, breaking joints like stringers, and form decks upon which the successive sections rest. The purlins are notched down 1 inch on the caps, and are also notched 1 inch to receive the sills of the bent resting upon them. The caps and sills of succeeding sections are bolted together. The purlins constitute the entire longitudinal bracing, excepting in the upper section, where diagonal braces *k*, *l* are employed. It would add considerably to the stability of the structure if similar braces were placed in every panel from the ground upwards. The plan shows but one dowel at each connection of post with sill. Two would be a better number, especially in the case of the outside batter posts and the counter posts *m*, *n*, *o*, and *p*.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 10 in. × 12 in. and 5 in. × 8 in., notched 1 in. over ties.

Ties, 6 in. × 8 in. × 16 ft., notched 1 in. over stringers.

Track stringers, 9 in. × 16 in. × 32 ft., notched 1 in. over caps.

Jack-stringers, 7 in. × 16 in. × 32 ft.

Spreaders, 3 in. × 12 in.

Bents: Caps, 12 in. × 14 in. × 16 ft.
Plumb posts, 12 in. × 12 in.
Batter posts, 12 in. × 12 in.
Intermediate caps and sills, 12 in. × 14 in.

Sway-Bracing: Horizontal, 6 in. × 10 in.
Diagonal, 6 in. × 10 in.

Main sill, 12 in. × 14 in.

Longitudinal Bracing: Horizontal, 6 in. × 10 in.
Diagonal, 6 in. × 10 in.

Purlins, 12 in. × 12 in. × 18 ft.

DIMENSIONS OF IRON DETAILS.

Bolts: $\frac{3}{4}$ in. × 49 in.; floor system to caps.
$\frac{3}{4}$ in. × 41 in.; sills to caps of different decks.
$\frac{3}{4}$ in. × 37 in.; outside guard-rails to jack-stringers
$\frac{3}{4}$ in. × 27 in. } longitudinal bracing.
$\frac{3}{4}$ in. × $24\frac{3}{4}$ in. } longitudinal bracing.
$\frac{3}{4}$ in. × 23 in.; sway-brace splice, sill splice, horizontal sway-bracing to posts.
$\frac{3}{4}$ in. × 22 in.; stringer joints, packing bolts.
$\frac{3}{4}$ in. × 19 in.; sway-braces to posts.
$\frac{5}{8}$ in. × 11 in.; inside guard-rails to ties.

Drift-bolts: $\frac{3}{4}$ in. × 24 in.; sills to piles and stringers to caps.

Dowels: 1 in. × 6 in.; posts to caps and sills.

Spikes: Cut 60-penny; spreaders and brace blocks to caps.
Boat, $\frac{1}{2}$ in. × 9 in.; sway-braces to posts.

Cast Washers: Under head and nut of each bolt.

1795. Practical Suggestions.—In practically all trestles on American roads, designs have, either intentionally or otherwise, placed the stringers directly over the posts and the rails directly over the stringers, so that the shock of the passing train is communicated directly to the post through the tie and stringer, and through the post to the hard, unyielding foundation. The effect of this can not be other than to place unnecessary stress upon particular timbers, and to subject both rolling stock and foundation to unnecessary shock.

In most trestles, whether pile or framed, the stringers are placed directly above the inside posts or piles, which are usually vertical, and, consequently, must take practically all the load until from some cause or other these inside posts or piles settle, and then, and not until then, is a part of the load transferred through the cap to the outside posts or

piles. It is evident that if the stringers were placed midway between the posts or piles, the load would be practically divided between them; and, as there would then be a short distance from the stringer to each post, some of the shock, at least, would be taken up by the cap. If, now, instead of placing the stringer with its center directly under the rail, it were moved say 6, 9, or 12 inches outwards from the rail, the ties would act partly as beams, and a part of the shock would be taken up by them. By arranging the posts or piles as before suggested, a further portion of the shock would be taken up by the cap, leaving a much smaller proportion of it to be transferred by the posts to the foundation, and, through recoil, to the passing train. Now, if

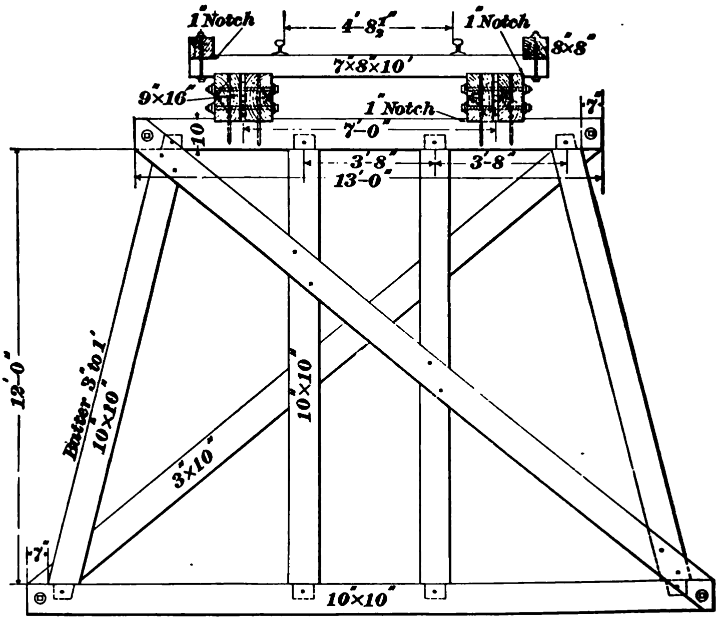


FIG. 623.

under the present system the great share of the load is carried (and, apparently, with safety) by the vertical posts, would not an equal load be carried with equal safety by

smaller timbers so arranged that each shall perform its full proportion of work ?

In iron bridges the floor system is so arranged that the ties shall act as beams, and there is no reason why the floor system of a trestle bridge should not be arranged in the same way. The only objection to moving the stringers from under the rail is that in case of derailment the weight of the derailed engine or car would, through the wheels, be concentrated upon only a few ties. To obviate this danger, or, at least, greatly reduce it, the ties should be placed near together, with not more than 6 inches of clear space between them. This would practically form a solid floor, upon which the wheels would run without danger of *bunching* the ties. The guard-rail should be not more than 12 inches from the rail, and should be not less than 7 in. × 8 in. in cross-section, notched 1 inch over the ties, and bolted to at least every fourth tie. With such an arrangement of parts, posts, caps, and sills 10 in. × 10 in. in cross-section would meet every requirement.

1796. A trestle plan embodying these ideas is given in Fig. 628, and recommended to the student for practical study and work. From the plan it will be seen that in case of derailment, so long as the guard timbers hold, the outside wheels of the derailed trucks will bear directly upon the stringer, which absolutely insures the ties against breaking. The ties, being strongly supported at both ends, can not be broken by the inside wheels of the derailed trucks, unless they are weakened by decay. To prevent bunching, the ties must, as stated above, be placed so close together that derailed wheels will roll over them. The caps, posts, and sills are considerably smaller than those used on most railroads, special exception being made in the case of the Pennsylvania Railroad, already noted. The stringers, on the other hand, are increased in section from 8 in. × 16 in., a size widely adopted, to 9 in. × 16 in., and are amply strong for spans of 14 feet. The guard-rails are also increased in size above that generally employed. The caps and sills

extend in length but 7 inches beyond the batter posts; whereas, many standards call for an extension of from 12 to 18 inches. Mortises and tenons are 3 in. × 5 in. × 7 in., with treenails of either white oak or locust. In pile trestling, the piles will be spaced precisely as the posts in the framed structure.

FRAMED TRESTLE.

DIMENSIONS OF TIMBERS.

Floor System:

Guard-rails, 8 in. × 8 in. × 20 ft., notched 1 in. over ties.
Ties, 7 in. × 8 in. × 10 ft., notched 1 in. over stringers.
Stringers, 9 in. × 16 in. × 28 ft., notched 1 in. over caps.

Bents: Caps, 10 in. × 10 in. × 13 ft.
Plumb posts, 10 in. × 10 in.
Batter posts, 10 in. × 10 in.
Sway-braces, 3 in. × 10 in.
Sill, 10 in. × 10 in.

DIMENSIONS OF IRON DETAILS.

Bolts: $\frac{3}{4}$ in. × $15\frac{1}{2}$ in.; guard-rails to ties, a bolt in every fourth tie.
$\frac{3}{4}$ in. × $21\frac{1}{2}$ in.; through stringers at separators.
$\frac{3}{4}$ in. × $15\frac{1}{2}$ in.; sway-braces to cap and sill.

Drift-bolts: $\frac{3}{4}$ in. diam. × 23-in. stringers to caps.

Treenails: 1 in. × 10 in.

SIMPLE WOODEN TRUSS BRIDGES.

1797. The period of construction is a trying one to even the strongest companies, and any expenditure which can either be avoided or put off until this trying period is past should not be incurred. This will explain why so many wooden structures are erected on newly constructed lines, instead of those composed of iron and steel.

Three forms of trusses will be considered in this chapter, though only the last is employed for bridges for standard gauge railroads. The first and second forms are suited to bridges for narrow-gauge railroads, street-car lines, and highways.

The parts will be proportioned for the maximum loads to which they will be subjected; and, instead of the concentrated wheel loads, the equivalent live and dead loads per lineal foot of span will be used.

Before commencing the subject of trusses, a limited space will be given to the subject of the materials entering into these structures, their comparative strength and the methods by which the stresses upon the various parts are determined, and the parts proportioned to resist these stresses.

1798. Bridge Timber.—The principal varieties of timber used in bridge building are:

White Pine.
Spruce.
Long-Leaf Yellow Pine.
Short-Leaf Yellow Pine.
White Oak.

Of these, long-leaf yellow pine, on account of its great strength and the fact that it may be had in any desired length, is more used in bridge building than the other four varieties combined. On the Pacific Slope, Washington fir is first in demand, and by most engineers it is considered superior to the long-leaf pine.

1799. Forces Operating in Bridges.—The forces to which the timber in a bridge is subjected manifest themselves in *shearing*, *crushing*, *bending*, and *breaking*. These forces the student has already become familiar with in his study of the subject of Strength of Materials.

1800. Transverse Strength of Materials.—The transverse strength of a material is that by which it resists breaking. Now, it has been determined by actual experiment that in beams of the same material and exactly alike except in breadth, their strengths vary in the same proportion as those breadths, i. e., if one is two, three, or ten times broader than the other, its strength will be two, three, or ten times as great. If they are alike except in their

lengths, their strength will vary inversely as their lengths, i. e., if one is two, three, or ten times as long as another, it will be only one-half, one-third, or one-tenth as strong. If they are alike except in point of *depth*, their strengths will vary as the *square* of those depths, i. e., if one has a depth two, three, or ten times that of another, it will be four, nine or one hundred times as strong. From this it follows that the strength of any beam, of any size, of any material, is in proportion to

$$\frac{\text{its breadth in inches} \times \text{square of its depth in inches}}{\text{its length in feet}},$$

and if we find by actual trial what center load will break a beam of known size, and then find the ratio between

$$\frac{\text{its breadth in inches} \times \text{square of its depth in inches}}{\text{its length in feet}}$$

and its breaking load, this ratio will be that which any similar beam of the same material has to its breaking load.

For example, if we take a piece of sound, straight-grained spruce, 4 inches broad and 8 inches deep, and place it horizontally upon two supports 8 feet apart, we shall find by gradually loading the beam at its center that the breaking load, including half the weight of the beam itself, is 14,400 lb. Substituting these given dimensions in the fraction

$$\frac{\text{the breadth in inches} \times \text{square of the depth in inches}}{\text{length in feet}},$$

we have $\frac{4 \times 64}{8} = 32$, and the ratio between 14,400 and $32 = \frac{14,400}{32} = 450$. This ratio is called the **constant** for the center breaking load for beams of spruce, and to find the center breaking load for any beam of the same material we take its dimensions and substitute them in the following formula:

$$\textit{center breaking load} = \frac{\textit{breadth in inches} \times \textit{square of depth in inches}}{\textit{length in feet}} \times C. \quad \textbf{(127.)}$$

In this formula, C is a constant depending on the kind of timber, and its value for four of the most commonly used varieties is given in Table 52.

EXAMPLE.—A spruce beam is 8 in. broad, 12 in. deep, and 20 ft. long; what is its center breaking load ?

SOLUTION.—Substituting the given dimensions in the above formula, we have, using the value for C given in Table 52 for spruce,

$$\text{center breaking load} = \frac{8 \times 144}{20} \times 450 = 25{,}920 \text{ lb. Ans.}$$

One-half the weight in pounds of the beam itself must be deducted from this result to obtain the *neat* center load.

1801. Factor of Safety.—In order that a structure may endure, no part of its framework should be strained to the limit of its strength. The ratio between the ultimate or breaking load of a beam and the working load, which is the actual load placed upon it, is called the **factor of safety.** This factor of safety will vary, according to the character of the structure and the nature of the strains to which it will be subjected. Roof trusses which, except in cases of violent storms, support a quiescent load consisting of the roof covering, snow, ice, etc., together with their own weight, may have a factor of safety as low as 3. But for bridges, especially those carrying locomotives and heavy trains, where the strains are sudden and violent, a factor of safety of at least 6 should be used; and for those on important lines, a factor of 8 is none too great. Hence, in the preceding example, the beam whose ultimate center load is 25,920 lb., if used in a railroad bridge, should not be subjected to a greater center load than $\frac{25{,}920}{6} = 4{,}320$ lb.

1802. Table of Constants.—By actual experiment, not only with small specimens of timber (usually 1 inch square and 12 inches between supports), but with full-sized beams, the center breaking loads for many varieties of timber and their constants have been determined. The varieties of timber most used in bridge building, together with their

constants for center breaking loads, are given in the following table. For highway bridges, use a factor of safety of 5; for street car bridges, a factor of 6, and for railroad bridges, a factor of 7 or 8:

TABLE 52.

CONSTANTS FOR CROSS BREAKING CENTER LOADS.

Material.	Pounds.
Hemlock	400
White Pine and Spruce	450
Southern Long-Leaf Yellow Pine	550
White Oak	600

1803. Inclined Beams.—When the beam, instead of being horizontal, is inclined, the horizontal distance between the points of support must be taken as the span.

1804. To find the side of a square horizontal beam of given span, supported at both ends and required to break under a given quiescent center load:

Rule.—*Multiply the clear span in feet by the given breaking load in pounds. Divide the product by the corresponding constant, Art.* **1802.** *Take the cube root of the quotient. This cube root will be the required breadth or depth of the beam, approximately, in inches.*

When the size of the beam is so great that its weight must be taken into consideration, provide for this additional weight by increasing the size of the beam as follows: Calculate the weight of the beam already obtained Then say, *as the center load is to half this weight, so is the breadth found to a new breadth to be added to it.* It will still be

somewhat too small, owing to the weight of the breadth last added. This additional weight may be easily found and provided for by adding to the breadth.

EXAMPLE.—What is the side of a square horizontal white pine beam, 12 ft. long between supports, which will break under a quiescent center load of 50,000 lb.?

SOLUTION.—$50,000 \times 12 = 600,000$; $600,000 \div 450$, the constant for white pine, $= 1,333$. The cube root of 1,333 is 11, almost exactly; hence, a horizontal beam 11 inches square and 12 feet between supports will break under a quiescent center load of 50,000 lb. Ans.

In this case, no account is taken of the weight of the beam, which is so small in comparison to its center breaking load that it may be ignored.

1805. To find the side of a square horizontal beam which will safely bear a given center load:

Rule.—*Multiply the given load by the number of times it is exceeded by the breaking load. Then find by Art.* ***1804*** *the side of a square beam to break under this increased load. The beam thus found will be, approximately, the safe one for the actual load, exclusive of the weight of the beam itself. If this weight must be included, provide for it by increasing the breadth, as directed in Art.* ***1804.***

EXAMPLE.—What should be the side of a square beam of white pine placed horizontally with 10 feet between supports to safely bear a center load of 12,000 lb., with a factor of safety of 6?

SOLUTION.—12,000 lb. $\times 6 = 72,000$ lb., the center breaking load for the beam. $72,000 \times 10 = 720,000$. $720,000 \div 450$, the constant for center breaking loads for white pine, $= 1,600$. The cube root of $1,600 = 11.7$. Hence, the side of the square is 11.7 in. Ans. By increasing the side of the square to 12 inches, we make ample allowance for the additional weight of the beam.

1806. To find the breadth of a horizontal rectangular beam, supported at both ends, to break under a given quiescent center load, the span and depth of beam being given:

Rule.—*Multiply the center load in pounds by the span in feet. Multiply the square of the depth in inches by the*

constant, Art. 1802. Divide the first product by the last. The quotient will be, approximately, the breadth.

If the weight of the beam is so great that it need be taken into consideration, provide for this increased weight by increasing the size of the beam, as directed in Art. **1804.**

EXAMPLE.—A horizontal beam of yellow pine is 18 ft. between supports; the depth of the beam is 12 in.; what should be the breadth of the beam to break under a quiescent center load of 50,000 lb.?

SOLUTION.—$50,000 \times 18 = 900,000$ lb. The constant for the breaking center load of yellow pine is 550 (Art. **1802**). The depth, 12, squared $= 144$; $144 \times 550 = 79,200$; $900,000 \div 79,200 = 11.36$, the breadth of the required beam. Ans. By increasing the breadth to 12 inches, the increased center load due to the weight of the beam itself is more than provided for.

1807. To find the depth of a horizontal rectangular beam, supported at both ends, which shall break under a given quiescent center load, the breadth of the beam and length of span being given:

Rule.—*Multiply the load in pounds by the span in feet. Multiply the breadth in inches by the constant given in Art. 1802. Divide the first product by the last; take the square root of the quotient for an approximate depth. Calculate the weight of a beam having the depth already found; add half its weight to the given center load, and with the new load repeat the calculation; the result will be close enough for practical purposes, though not exact, owing to the neglect of the weight of the depth last added.*

EXAMPLE.—A rectangular horizontal beam of yellow pine is 9 in. broad and 16 ft. between supports; what should be the depth of the beam to break under a quiescent center load of 24,000 lb.?

SOLUTION.—$24,000 \times 16 = 384,000$ lb. The constant for yellow pine (Art. **1802**) is 550. $550 \times 9 = 4,950$. $384,000 \div 4,950 = 77.57$. $\sqrt{77.57} \doteq 8.8$ in. A beam of these dimensions, viz., 9 in. $\times$ 8.8 in. $\times$ 16 ft., will contain 15,206 cu. in. $= 8.8$ cu. ft. Yellow pine weighs on an average 45 lb. per cu. ft. Hence, the beam weighs $45 \times 8.8 = 396$ lb. $396 \div 2 = 198$ lb., which, added to 24,000 lb., the given center load, gives 24,198,

the total center load of the beam. $24,198 \times 16 = 387,168$. $387,168 \div 4,950 = 78.22$, the square root of which is 8.84, the required depth of the beam in inches. Ans.

From this result the student will see that in providing for the weight of the beam the depth of the beam is increased only .04 inch, an amount so small that it may be ignored. In actual practice this depth would be increased to 9 inches.

1808. Strength of Wooden Pillars.—The strength of wooden pillars, like that of wooden beams, depends much upon their *degree of seasoning*. Thoroughly seasoned sticks will often support twice as great a load as green ones. This fact should be borne in mind when erecting structures of imperfectly seasoned timber. For permanent structures, timber should not be subjected to more than from $\frac{1}{8}$ to $\frac{1}{6}$ of its crushing load.

The following formula by Charles Shaler Smith is for the breaking loads of square or rectangular pillars or posts of moderately seasoned white or yellow pine, with flat ends, firmly fixed and equally loaded:

Calling either side of the square or the least side of the *rectangle* the *breadth*, we have

Breaking load in pounds per square inch of area of pillar of white or yellow pine =

$$\frac{5,000}{1 + \left(\frac{\text{square of the length in inches}}{\text{square of breadth in inches}} \times .004\right)}, \qquad \textbf{(128.)}$$

in which 5,000 equals the breaking load in pounds per square inch for short blocks.

EXAMPLE.—A pillar of white pine is 10 inches square and 8 feet long; what is its safe load with a factor of safety of 6?

SOLUTION.—The length equals 8 ft. = 96 in. $96^2 = 9,216$. The square of the breadth $= 10^2 = 100$. Applying the given formula, we have

Breaking load in pounds per square inch of area =

$$\frac{5,000}{1 + \left(\frac{9,216}{100} \times .004\right)} = \frac{5,000}{1.37} = 3,650 \text{ lb.}$$

As this is the breaking load, and a factor of 6 is required, the safe load per square inch will be $3,650 \div 6 = 608$ lb., nearly, and for 100 square inches, the area of the pillar, the safe load will be $608 \times 100 = 60,800$ lb. Ans.

EXAMPLE.—A rectangular pillar is 8 in. × 10 in. × 12 ft.; what is its safe load with a factor of safety of 4?

SOLUTION.—Applying the above formula, we have

Breaking load in pounds per square inch of area =

$$\frac{5,000}{1 + \left(\frac{144^2}{8^2} \times .004\right)} = \frac{5,000}{2.3} = 2,174 \text{ lb.},$$

the breaking load per square inch. With a factor of safety of 4, we find the safe load to be $2,174 \div 4 = 543$ lb. per sq. in. The area of the pillar is $8 \times 10 = 80$ sq. in., and $543 \times 80 = 43,440$ lb. Ans.

In applying this formula to composite columns, made up of several sticks bolted together at intervals, give to each stick its proportionate share of the total load to be carried by that member, and then assume that it stands alone and unsupported. This is the only safe rule. Even though the sticks are firmly bolted together with packing-blocks notched into the sides, they should never be assumed to act as one solid stick, as the packing-blocks and washers are sure to grow loose in time.

1809. Shearing and Crushing.—For shearing and crushing it is generally safe to use a factor of safety of 2 or 3. Use for *working values* of the shearing stress *along the grain*, for

White pine and spruce........	200 lb. per sq. in.
Long-leaf yellow pine.........	400 lb. per sq. in.
Short-leaf yellow pine.........	300 lb. per sq. in.
White oak....................	600 lb. per sq. in.

For crushing *across the grain*, take for working values of seasoned timber, for

White pine and spruce........	300 lb. per sq. in.
Long-leaf yellow pine.........	500 lb. per sq. in.
Short-leaf yellow pine.........	450 lb. per sq. in.
White oak....................	1,000 lb. per sq. in.

For crushing *endwise* (short blocks), take for working values for

White pine....................2,500 lb. per sq. in.
Long-leaf yellow pine.........3,000 lb. per sq. in.
Short-leaf yellow pine.........2,800 lb. per sq. in.
White oak .... .2,750 lb. per sq. in.

1810. Tension.—Wood fiber is much stronger in tension than in any other way, and, as a result, it may be said that wood seldom or never breaks in pure tension in actual service. In long sticks in tension, the grain runs more or less across the line of the stick, and a liberal allowance must be made for the reduction of the stick by framing it. In actual work, it is not well to rely upon a working stress in tension of more than 2,000 or 3,000 pounds per square inch for ordinary bridge timber.

EXAMPLES FOR PRACTICE.

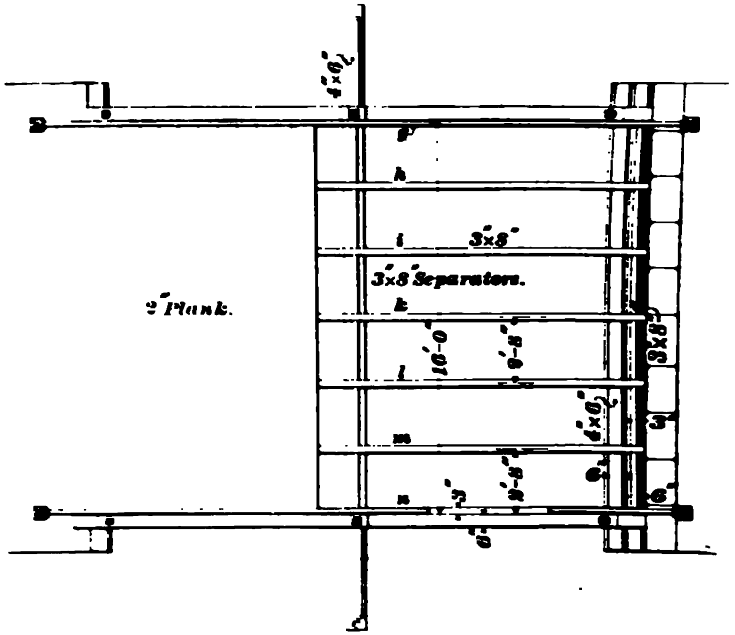
1. A stick of white pine is subjected to a shearing stress along the grain of 40,000 lb.; how many square inches of surface are necessary to sustain this stress with a factor of safety of 3?

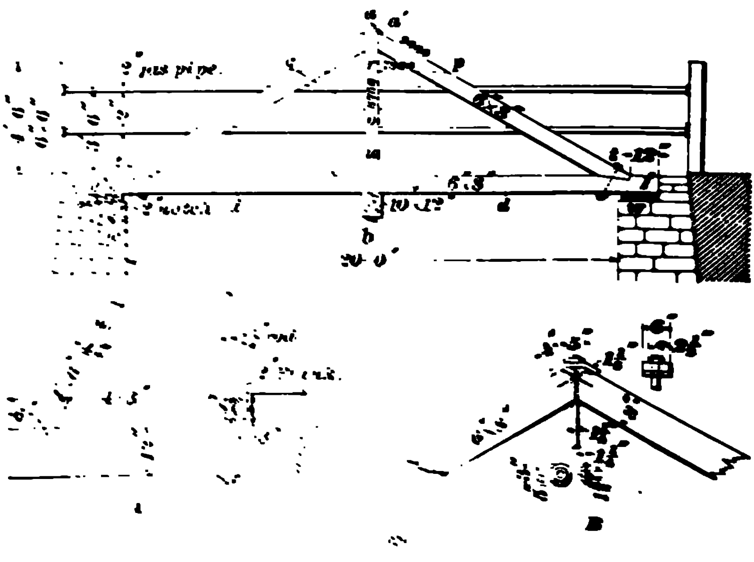
SOLUTION.—From Art. **1809,** we find the safe working value for shearing stress per square inch along the grain for pine is 200 lb., and to sustain a stress of 40,000 lb., it will require as many square inches of surface as 200 is contained in 40,000, which is 200 sq. in. Ans.

2. An oak tie-beam is subjected to a shearing stress across the grain of 62,000 lb.; how many square inches of surface are necessary to sustain this stress? Ans. 103.3 sq. in.

1811. To find the safe dimensions for a rectangular horizontal beam of given span, supported at both ends, and which is at the same time subjected both to a transverse strain and to a longitudinal tensile or pulling one, or to a longitudinal compressive one:

Rule.—*When the longitudinal strain is tensile, find separately the safe dimensions as if for a beam alone, and as if for a tie alone, and add the two resulting areas together. When the longitudinal strain is compressive, find separately*


4"×6"
3"×8"
3"×8" Separators.
2" Plank.
10'-0"
9'-8"
3"×8"
4"×6"
2" gas pipe.
6"×8"
10"×12"
20'-0"


B

the safe dimensions as if for a beam alone, and as if for a pillar alone, and add the two resulting areas together.

EXAMPLE.—A rectangular horizontal beam of yellow pine of 14 feet span is to sustain a uniformly distributed transverse load of 40,000 lb., and a pulling stress of 30,000 lb., with a factor of 6; what should be the dimensions of the beam ?

SOLUTION.—A uniformly distributed load of 40,000 lb. is equivalent to a center load of 20,000 lb. A safe center load of 20,000 lb. with a factor of 6 is equivalent to a center breaking load of 120,000 lb. Applying the rule given in Art. **1804**, we have $120,000 \times 14 = 1,680,000$. The constant for center breaking loads for yellow pine (Art. **1802**) is 550. $1,680,000 \div 550 = 3,054$, the cube root of which is 14.5. This gives in inches the side of a square beam which will safely carry the given load.

From Art. **1810** we conclude the safe working stress in tension per square inch for yellow pine to be, say 3,000 lb. per square inch. The given tensile stress is 30,000 lb., to resist which it will require as many square inches as 3,000 is contained in 30,000, which is 10. We, therefore, add 10 sq. in. to area of the given beam by increasing either the breadth or depth $\frac{7}{10}$ of an inch. Ans.

1812. Bridge Loads.—The trusses will be proportioned for the following loads, viz:

Highway bridges, combined live and dead load equivalent to 1,500 pounds per lineal foot.

Street car bridges, combined live and dead load equivalent to 4,000 pounds per lineal foot.

Railroad bridges, combined live and dead load equivalent to 6,000 pounds per lineal foot.

The foregoing are the maximum loads to which they will be subjected.

The forms of trusses given will not be used for spans exceeding 30 feet for railroads, or 40 feet for highways. Where larger spans occur, other and more complicated forms of trusses will be employed, the designing of which properly belongs to the bridge department.

1813. King-Rod Truss.—The simplest form of a bridge truss is shown in Fig. 629. This is called a king-rod truss, from the rod *a b*, which extends from the head *a* of the rafters to the base *b* of the needle-beam *c*. Heavy cast

washers are placed under both head and nut of the king-rod, and when the nut is tightened, all parts of the truss are put under strain.

Let *d*, *d* be points half way between the king-rod and the abutments *w*, *w*; then, the king-rod *a b* will sustain all the weight resting upon the beam *e f*, between the points *d*, *d*; also, half the weight of the needle-beam *c*, and of the load resting upon it. From an inspection of the plan, it will be readily seen that all that portion of the bridge between the points *d*, *d* and the abutments *w*, *w* is supported by the abutments. The entire weight of the truss and its load is sustained ultimately by the abutment walls, but the portion *d*, *d* reaches them by first traveling up the king-rod *a b* to the head of the rafters and then down them to their feet, where it is transmitted directly to the abutments.

From an inspection of the plan, it will be readily seen that all of the floor-beams *g*, *h*, *i*, *k*, *l*, *m*, and *n* rest upon the needle-beam, and, instead of one span of 20 feet, they form two spans of 10 feet each, which permits us to use much smaller floor beams than would be required for a span of 20 feet. Assuming that the total dead load (i. e., the load of the structure itself) and the live load (i. e., the load placed upon the bridge, but distinct from the weight of the structure itself) are equivalent to 100 lb. per sq. ft. of bridge floor, we have the total load carried by two king-rods equal to $10 \times 17 \times 100 = 17{,}000$ lb., and for one king-rod the load is $\frac{17{,}000}{2} = 8{,}500$ lb.

Let the height of the peak *a* of the truss be 6 feet above the tie-beam *e f*. Draw the rafters conforming to the dimensions given in the plan. Draw the line *a b*, representing the king-rod, and lay off upon it downwards from *a'* to a scale of 10,000 lb. to the inch, the distance $a'o = 8{,}500$ lb. Complete the parallelogram *a' q o p* and draw the diagonal *q p*. Then *a' p* and *a' q* will measure the stresses upon the rafters due to the weight upon the king-rod, and *r p* and *r q* the pulling forces produced by the same weight; but they act along the tie-beams in opposite directions,

causing a stress equal to one of them throughout the tie-beam.

To resist the stress $a\,p$ or $a\,q$, running lengthwise through the rafter from head to foot, *the rafter must be regarded as a pillar*, and the safe area required to resist this stress we find by applying formula **128,** given in Art. **1808,** viz.:

Breaking load in pounds per square inch of area of yellow pine =

$$\frac{5{,}000}{1+\left(\frac{\textit{square of length in inches}}{\textit{square of breadth in inches}} \times .004\right)}.$$

The length of rafter as measured along its center line from joint to joint is 11 ft. 6 in. = 138 in.

Assuming a breadth of 6 in. for the rafters, we have

Breaking load in pounds per square inch of area =

$$\frac{5{,}000}{1+\left(\frac{138^2}{6^2} \times .004\right)} = 1{,}604 \text{ lb.},$$

which, with a factor of safety of 8, gives a safe load of $\frac{1{,}604}{8} = 200$ lb. per sq. in.

The stress $a'\,p$ measured by the given scale equals 9,000 lb.; hence, the area required to resist this stress will be $\frac{9{,}000}{200} = 45$ sq. in. The breadth of the rafter has been assumed as 6 inches; hence, the depth must be $\frac{45}{6} =$ $7\frac{1}{2}$ inches. Since the usual market sizes of timber run only in even inches, we will make the depth of the rafter 8 inches.

In this bridge the plank flooring does not rest directly upon the tie-beams, but upon the floor-beams g and n, which are spiked to the tie-beams. The tie-beams are gained 2 in. to form footings for the rafters, and the tie-rods pass through them, reducing their actual span to 10 ft., one-half the total span of the bridge. If the tie-beams were given smaller dimensions than the rafters, they would appear weak, and, though unnecessarily large, we give them the same dimensions, viz., 6 in. × 8 in.

We determine the dimensions of the needle-beam c by first finding the load which it must sustain. The king-rods support the needle-beam, which in turn supports the tie-beams, floor-beams, and floor, and, hence, both sustain practically the same load. The total uniform load we have already determined to be 17,000 lb., which is equivalent to a center load of 8,500 lb. This gives, with a factor of safety of 6, a center breaking load of $8,500 \times 6 = 51,000$ lb. The span from center to center of king-rods is 16.5 ft. Assuming for the needle-beam a depth of 12 in., we have, from Art. **1806,**

$$\text{required breadth} = \frac{51,000 \times 16.5}{12^2 \times 550} = 10.6 \text{ in.}$$

As it is safe to say that the bridge will never be loaded to these limits, owing to the difficulty of loaded teams passing on the bridge, we make the breadth of the needle-beam an even 10 in.

The floor-beams have a clear span of 9 ft. 7 in., or 9.58 ft. The distance from center to center of floor-beams is 2 ft. 8 in., or 2.66 ft. Hence, the total distributed load on each beam, at 100 lb. per sq. ft., is $2.66 \times 9.58 \times 100 = 2,548$ lb., equal to a center load of $\frac{2,548}{2} = 1,274$ lb. Allowing a factor of safety of 8, we have a center breaking load of $1,274 \times 8 = 10,192$ lb.

Assuming for floor-beams a depth of 8 in., we find from Art. **1806,**

$$\text{required breadth} = \frac{10,192 \times 9.58}{8^2 \times 550} = 2.77 \text{ in.}$$

This breadth we increase to 3 in., the standard dimension nearest to the one required, making the cross-section dimension of the floor-beams 3 in. $\times$ 8 in. Their length should be equal to the total length of the bridge, or 23 ft. The floor-beams and stringers do not come in direct contact with the stone abutments, but rest upon timbers s, s, called wall plates, by means of which the weight of the bridge is distributed over the entire bridge seat. The wall plates are of

oak timber, 4 in. by 6 in., and extend the full length of the abutments.

The dimensions of the king-rod may be found in Table 53.

TABLE 53.

WEIGHTS AND STRENGTHS OF IRON BOLTS.

Ends Enlarged or Upset.			Ends Enlarged or Upset.		
Diameter of Shank.	Weight per Foot Run.	Breaking Stress.	Diameter of Shank.	Weight per Foot Run.	Breaking Stress.
Inches.	Pounds.	Pounds.	Inches.	Pounds.	Pounds.
$\frac{1}{2}$	.661	8,803	$1\frac{3}{4}$	8.10	102,368
$\frac{9}{16}$	.837	11,133	$1\frac{13}{16}$	8.69	109,760
$\frac{5}{8}$	1.03	13,754	$1\frac{7}{8}$	9.30	117,600
$\frac{11}{16}$	1.25	16,621	$1\frac{15}{16}$	9.93	125,440
$\frac{3}{4}$	1.49	19,779	2	10.6	133,728
$\frac{13}{16}$	1.75	23,296	$2\frac{1}{8}$	12.0	142,912
$\frac{7}{8}$	2.03	26,880	$2\frac{1}{4}$	13.4	160,384
$\frac{15}{16}$	2.33	30,912	$2\frac{3}{8}$	14.9	178,528
1	2.65	35,168	$2\frac{1}{2}$	16.5	198,016
$1\frac{1}{16}$	2.99	37,632	$2\frac{5}{8}$	18.2	218,176
$1\frac{1}{8}$	3.35	42,336	$2\frac{3}{4}$	20.0	239,456
$1\frac{3}{16}$	3.73	47,264	$2\frac{7}{8}$	21.9	261,632
$1\frac{1}{4}$	4.13	52,192	3	23.8	284,928
$1\frac{5}{16}$	4.56	57,568	$3\frac{1}{4}$	27.9	315,840
$1\frac{3}{8}$	5.00	63,168	$3\frac{1}{2}$	32.4	366,464
$1\frac{7}{16}$	5.47	68,992	$3\frac{3}{4}$	37.2	420,448
$1\frac{1}{2}$	5.95	75,264	4	42.3	478,464
$1\frac{9}{16}$	6.46	81,536	$4\frac{1}{4}$	47.8	508,480
$1\frac{5}{8}$	6.99	88,256	$4\frac{1}{2}$	53.6	570,080
$1\frac{11}{16}$	7.53	95,200	$4\frac{3}{4}$	59.7	635,040

The load which each king-rod sustains we found to be 8,500 lb. A rod which would safely sustain this load

with a factor of safety of 6 would break under a load of 8,500 × 6 = 51,000 lb.

Referring to the table, we find in the column headed *Breaking Stress*, the number most nearly corresponding to 51,000, which is 52,192 lb. This stress calls for a rod

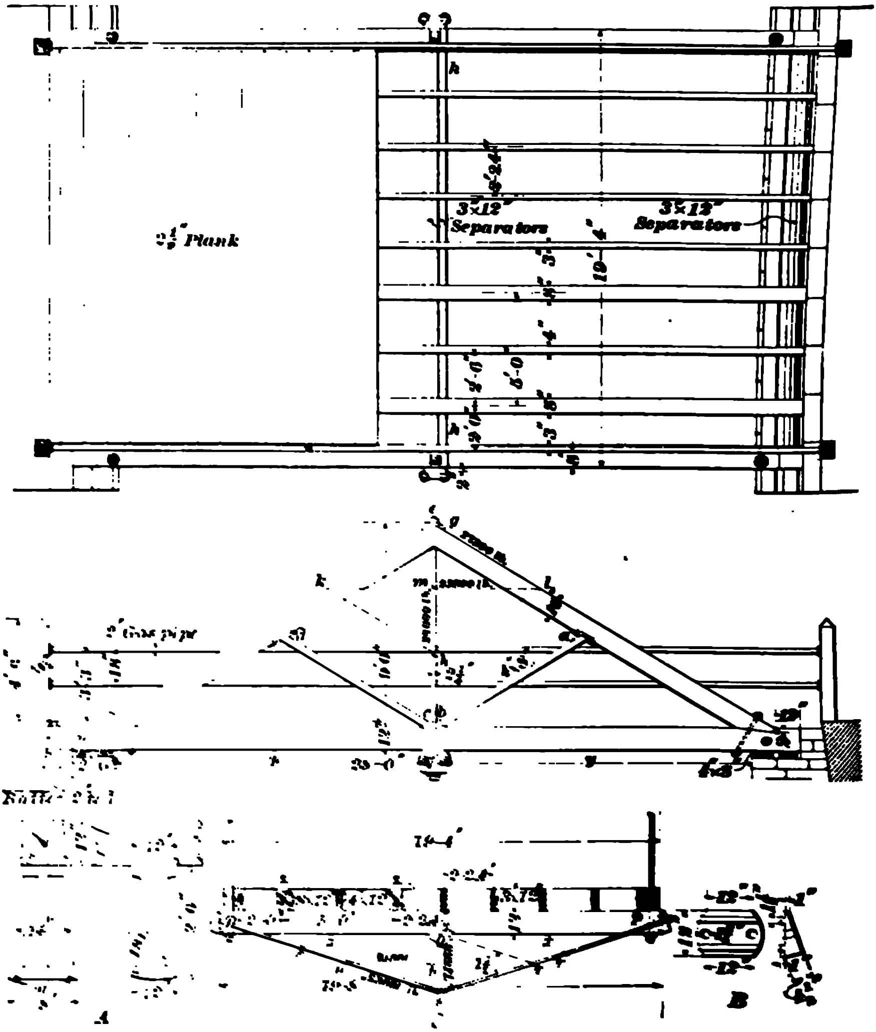


Fig. 636

$1\frac{1}{4}$ in. in diameter, which is the diameter we specify for king-rods.

The stress in the rafters produces a shearing stress along the grain of the tie-beam at the footing of the rafter. This stress is equal to $r\ p$, or 7,800 lb. We find in Art. **1809** that the working stress for shearing along the grain in yellow pine is 400 lb. per sq. in., and to resist a shearing stress of 7,800 lb. it will require $\frac{7,800}{400} = 19.5$ sq. in. There must accordingly be sufficient space between the foot of the rafter and the end of the stringer to give a superficial area of at least 19.5 in. As we have made this distance 12 in., giving a superficial area of $6 \times 12 = 72$ in., there is no question of the security of this joint. The bolts t, t passing through the tie-beam at the foot of the rafter serve only to keep the rafter in place. The needle-beam projects 4 ft. 3 in. outside the truss, as shown in detail at A. A brace u runs from this projecting needle-beam to the head of the rafters. It is fastened with spikes, and serves to stiffen the truss and prevent lateral vibration.

The joint of the rafters at their head, together with king-rod and washers, is shown in detail at B.

In Fig. 630 is illustrated another form of the king-rod truss, in which the stiffeners $a\ b$, $c\ d$ are introduced, their object being to stiffen the rafters and prevent their bending under the longitudinal stress transmitted to them by the king-rod. The stiffeners extend from the middle of the rafters to the base of the king-rod, where they abut against a cast-iron angle block. A cast-iron socket is let into the rafter at the head of each stiffener, and holds it securely in place. The angle block at the foot of the king-rod has two ribs which project 1 in. below the base of the block. Grooves are cut in the tie-beam to receive these ribs, which hold the angle block firmly in place. A hole is cast in the angle block through which the king-rod passes. The stiffeners practically reduce the length of the rafters to one-half their actual length, so far as their sustaining power as pillars is concerned.

The bridge shown in the figure is to accommodate the traffic of both street cars and highway. The parts are proportioned for an equivalent live and dead load of 4,000 lb. per lineal foot of bridge. The material is long-leaf yellow pine. The stresses are calculated as were those for the bridge shown in Fig. 629. The clear span of the bridge is 28 ft., and the breadth from outside to outside of truss is 19 ft. 4 in., and the height of truss above the tie-beams is 9 ft. The two king-rods $e f$ support that portion of the bridge and its load between the points y, y, or together, one-half the total load.

At 4,000 lb. per lineal foot, the load between y, y is $4,000 \times 14 = 56,000$ lb., one-half of which, or 28,000 lb., is carried by each king-rod. Accordingly, we lay out the outlines of the rafters, and though we do not yet know their depth, we can draw their upper edges, which will not alter their position, and form two sides of our parallelogram of forces. We next draw the line $e f$, which will be the center line of the king-rod. Upon this lay off from g, to a scale of 20,000 lb. to the inch, the distance $g h = 28,000$ lb. Complete the parallelogram $g l h k$. Then the equal sides $g l$ and $g k$ will represent by the same scale the longitudinal stress in the rafters. These stresses, which we find to be 27,300 lb., pass down the rafters and are taken up by the abutments. To resist these stresses, the rafters act as pillars. As before stated, the stiffeners $a b$ and $c d$ virtually reduce the length of these pillars, i. e., the rafters, to one-half their total length. Now, assuming that a rafter with a breadth of 8 in. will meet the requirements, we must find the requisite area of the rafter by the method given in Art. **1808.** The total length of the rafter measured along its center line is 16 ft. 6 in.; hence, the length of one pillar is one-half of the total length of the rafter, or 8 ft. 3 in., equal to 99 in.

Applying formula **128,** given in Art. **1808,** we have

Breaking load per square inch of area of pillar =

$$\frac{5,000}{1 + \left(\frac{99^2}{8^2} \times .004\right)} = \frac{5,000}{1.61} = 3,105 \text{ lb.}$$

With a factor of safety of 8, this rafter will bear per square inch of area, $\frac{3,105}{8} = 388$ lb.

The stress $g\ l$ upon this rafter is 27,300 lb., and to safely resist the stress it will require a rafter whose cross-sectional area is $\frac{27,300}{388} = 70$ sq. in. As we have assumed a breadth of 8 in., the depth will be $\frac{70}{8} = 8.75$ in.

The rafter must be notched on the under side to receive the cast-iron socket for the stiffener; consequently, it will be best to make the depth 10 inches, a size that is readily obtained in the market.

In the parallelogram $g\ l\ h\ k$, the diagonal $k\ l$ represents the pull along the tie-beam. Half of this stress $m\ l$ is in one direction from the foot of the king-rod, and half $m\ k$ in the other direction, making a uniform stress of $m\ l =$ 23,500 lb. throughout the tie-beam. The effect of this pull is to shear off the end of the tie-beam against which the rafter abuts. By reference to Art. **1809,** we find the safe shearing stress along the grain for yellow pine is 400 lb. per sq. in., and to resist a stress of 23,500 lb. it will require $\frac{23,500}{400} = 59$ sq. in., nearly. The distance from the foot of the rafter to the end of the tie-beam is 12 in. Assuming a breadth of 8 in. for the stringer, we will have to oppose the given stress of 23,500 lb., an area of $12 \times 8 = 96$ in., or nearly double the required area.

The stiffeners $a\ b$ and $c\ d$ support only half the weight of the rafter, and serve only to keep the rafter from bending under its longitudinal stress. If proportioned for their actual loads, they would appear weak and out of proportion. We accordingly make them 4 in. $\times$ 8 in.

The size of the king-rod we determine as follows: The load which it must sustain we have determined to be 28,000 lb. With a factor of safety of 6, its ultimate, or breaking, load will be $28,000 \times 6 = 168,000$ lb. By reference to Table 53, Art. **1813,** we find the diameter of a

bolt with a breaking stress of 168,000 lb. is nearly $2\frac{1}{4}$ in. We accordingly specify a $2\frac{1}{4}$-in. king-rod.

The king-rod passes through both tie-beam and needle-beam, being fitted at both head and nut with large cast washers.

As all floor-beams rest upon the needle-beam, it must therefore carry half the weight of the floor and its load, i. e., it must carry all the load between the points y, y. This we have already found to be $4,000 \times 14 = 56,000$ lb., a uniformly distributed load which is equivalent to a center load of $\frac{56,000}{2} = 28,000$ lb. The length of the needle-beam from center to center of king-rods is 18 ft. 8 in. A beam of this length and capable of bearing a center load of 28,000 lb. would be unwieldy. We accordingly truss the needle-beam by putting in a vertical strut q of cast iron at the center of the beam, and throw the stress upon the ends of the tie-beam by means of the rods r, r, thus converting a *transverse center load* into a *pull*. By this means we reduce the theoretical span of the needle-beam to one-half of its actual length. This truss is the reverse of the one just described, the strut q in the truss $p\ s\ p$ (see section C) taking the place of the king-rod $e\ f$ in the truss $n\ e\ o$.

The strut q supports one-half the load carried by the needle-beam, that is, all that part of its load between the two points x, x, and practically divides the needle-beam into two spans, each equal to one-half its length from center to center of the king-rods, or 9 ft. 4 in. long. Each of these beams will support one-half of the total load of the needle-beam, or 28,000 lb., which is a uniformly distributed load, and equivalent to a center load of $\frac{28,000}{2} = 14,000$ lb. With a factor of safety of 6, the center cross breaking load will be $14,000 \times 6 = 84,000$ lb. Assuming a breadth of 12 in. for the needle-beam, we determine its depth by Art. **1807.** The constant for center breaking loads for long-leaf yellow pine is 550 (Art. **1802**).

Substituting the known values in formula **127**,

$$\textit{center breaking load} = \frac{\begin{matrix}\textit{breadth} \\ \textit{in inches}\end{matrix} \times \begin{matrix}\textit{square of depth} \\ \textit{in inches}\end{matrix}}{\textit{length of span in feet}} \times C,$$

and denoting the required depth by x, we have

$$84{,}000 = \frac{12 \times x^2}{9.33} \times 550;$$

whence, $$x^2 = \frac{783{,}720}{6{,}600} = 118.75,$$

and $$x = 10.9 \text{ in., nearly,}$$

the required depth in inches of the needle-beam.

Making the length of the strut 2 ft. 6 in., we draw lines $p\ s$, $p\ s$ to denote the straining rods r, r of the truss. Laying off from s upwards, to a scale of 20,000 lb. to the inch, the distance $s\ t$ = 14,000 lb., the center load, we complete the parallelogram $s\ u\ t\ v$. The sides $s\ u$, $s\ v$ represent the stress in the straining rods r, r. By the given scale these sides measure 23,000 lb. This stress we divide between the two rods w, shown in section in the detail at A. The stress upon each rod is, therefore, $\frac{23{,}000}{2} = 11{,}500$ lb. With a factor of safety of 6, the breaking stress would be 11,500 × 6 = 69,000 lb. We accordingly look in Table 53 for the diameter of a rod with a breaking stress of 69,000 lb., and find it to be $1\frac{7}{16}$ in. To insure ample safety, we increase the diameter to $1\frac{1}{2}$ in. The pull placed upon the rods r, r places the needle-beam $p\ p$ under compression to an amount equal to $u\ y$, which, by the given scale, amounts to 21,500 lb. We find by reference to Art. **1809**, that for endwise crushing stress we may use a working stress of 3,000 lb. per sq. in. Hence, to resist this stress of 21,500 lb., we must add to the area of the needle-beam $\frac{21{,}500}{3{,}000} = 7.17$ sq. in., nearly. To hold the strut q in place, ribs cast with the strut fit into notches cut into the under side of the needle-beam. These notches, as well as those cut in the side of the needle-beam for the straining rods, somewhat reduce the area of

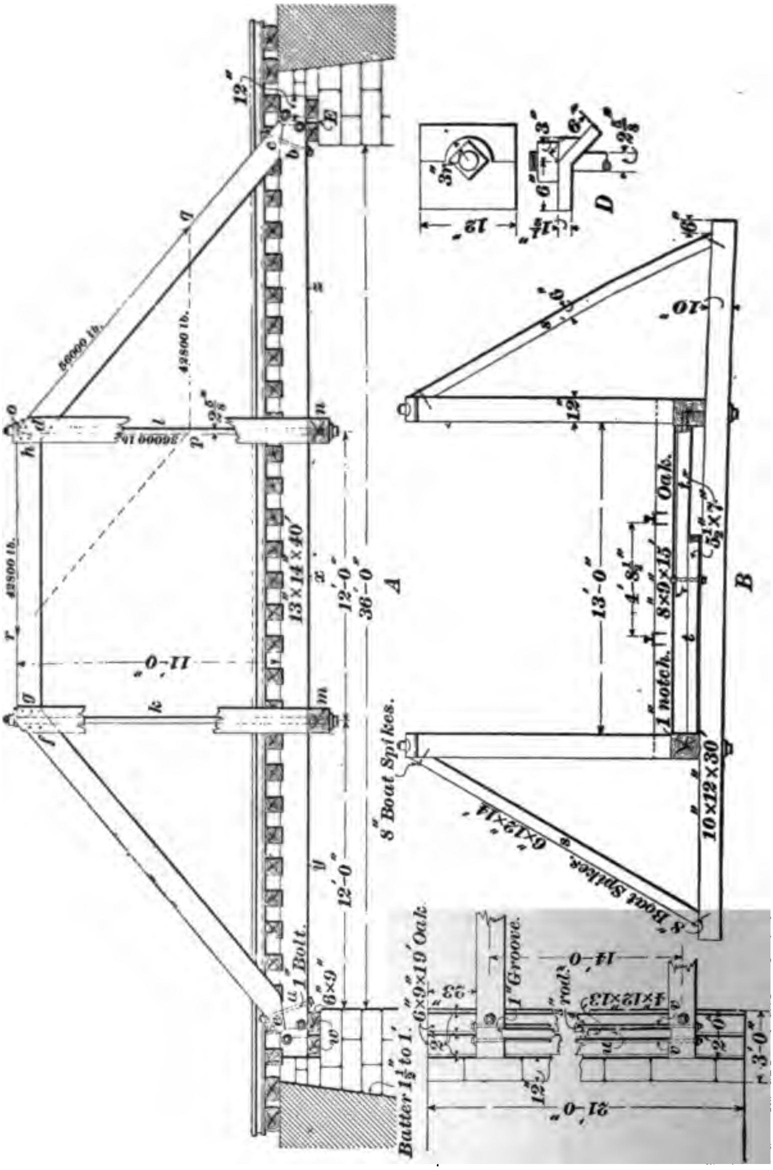

A
B
D
E
13"×14"×40"
12'-0"
36'-0"
11'-0"
8" Boat Spikes.
1" Bolt.
Batter 1½" to 1.
6"×9"×19' Oak.
56000 lb.
42800 lb.
1" Groove.
14'-0"
21'-0"
3'-0"
13'-0"
10×12×30
6×12×14
1 notch.
8×9×15
Oak.
8" Boat Spikes.

FIG. 681.

its cross-section, and to insure ample strength we increase the depth of the needle-beam to 12 in.

The straining rods are fitted at both ends with nuts and heavy cast washers which cover the entire end of the needle-beam, as shown in the cross-section *C*, and in detail at *B*. Ribs are cast on the backs of the washers, which fit into grooves cut into the ends of the needle-beam.

The floor system is so arranged that the street cars shall use only one side of the bridge, leaving the other side exclusively for vehicles. The rails are laid directly over stringers, which are proportioned to carry cars loaded to their utmost capacity.

A fully loaded street car weighs 10 tons. This is carried on a wheel base (the horizontal distance between the centers of wheels) of 6 ft. 6 in. Say this is equivalent to a center load of 7 tons, or $3\frac{1}{2}$ tons on each stringer. The depth of these stringers will, of course, be the same as that of the floor-beams, viz., 12 in. Their breadth we find by Art. **1806.** A safe center load of $3\frac{1}{2}$ tons, with a factor of safety of 7, would be equivalent to a breaking center load of $24\frac{1}{2}$ tons, or 49,000 lb. $\frac{49{,}000 \times 14}{12^2 \times 550} = \frac{686{,}000}{79{,}200} = 8.6$ in., the required breadth of track stringers. The factor of safety being large, and as a part of the load is distributed among adjacent floor-beams, we may safely specify for these stringers a breadth of 8 in.

1814. Queen-Rod Truss.—The form of truss shown in Fig. 631 is called a **queen-rod truss,** or, more briefly, a **queen truss.** The essential features of this truss, and those which distinguish it from the king-rod truss already described, are the *two* **queen-rods** *k*, *l* and the **straining beam** *g h*. The remaining parts, viz., the tie-beam *a b*, the rafters *c d* and *c f*, and the needle beams *m* and *n*, are similar to those found in the king-rod truss, or king truss.

This form of truss is frequently used for short spans, on new railroad work, especially if timber is abundant and economy in cost a first consideration.

The height of the truss should be such that the slope of the rafters will be approximately 45°, which is the angle at which a brace exerts its greatest strength. The queen-rods should divide the *clear span* (the space between the abutments) into three equal parts.

In Fig. 631 the span is 36 ft. in length, the height of the truss above the tie-beam is 11 ft., and the queen-rods divide the span into three equal parts of 12 ft. each. The points y and z are midway between the abutments and the queen-rods, and the point x is midway between the queen-rods. The queen-rod k supports its own weight and that part of the truss included between the points x and y, together with its load; the queen-rod l supports its own weight, together with that part of the truss included between the points x and z and its load. The parts of the truss between the abutments and the points y and z are supported by the abutments.

The truss shown in Fig. 631 is designed for a railway of standard gauge, and for an equivalent dead and live load of 6,000 lb. per lineal foot of span. The load for each truss per lineal foot will, therefore, be $\frac{6,000}{2} = 3,000$ lb. The distance $x\ z$ is 12 ft. The load upon the queen-rod l will, therefore, be $3,000 \times 12 = 36,000$ lb., and with a factor of safety of 6, the ultimate or breaking stress will be $36,000 \times 6 = 216,000$ lb., which, from Table 53, we find is the breaking stress for a rod of $2\frac{5}{8}$ in. diameter.

We accordingly lay off from o, on the center line of the queen-rod, to a scale of 20,000 lb. to the inch, the distance $o\ p$, equal to 36,000 lb. We then complete the parallelogram $o\ r\ p\ q$, and find that the stress of 36,000 lb., which the queen-rod l sustains, passes to the head o of the rod, where it is converted into two longitudinal stresses, one of which $o\ q$ travels down the rafter $c\ d$, and is taken up by the abutment E, while the other $o\ r$ moves in the direction $o\ r$. An equal stress is placed upon the straining beam by the load carried by the queen-rod k. This stress moves in the direction $g\ h$. These two stresses reacting upon each

other produce a stress throughout the straining beam equal to one of them. This stress *o r*, we find by the given scale of forces, amounts to 42,800 lb. The stress *o q*, by the same scale, amounts to 56,000 lb. The rafter *c d*, in resisting this stress, acts as a pillar. In determining the dimensions of this rafter, we will assume a certain breadth, say 12 in., and then find the depth necessary to sustain the given load, the variety of timber used being yellow pine. The length of the rafter is 16 ft. 4 in. = 196 in.

From formula **128,** Art. **1808,** we have

Breaking load per square inch of area of pillar =

$$\frac{5{,}000}{1 + \left(\dfrac{\textit{square of length in inches}}{\textit{square of breadth in inches}}\right) \times .004}.$$

Substituting given values, we have

Breaking load per square inch of area of pillar =

$$\frac{5{,}000}{1 + \left(\dfrac{196^2}{12^2} \times .004\right)} = \frac{5{,}000}{2.07} = 2{,}415 \text{ lb.}$$

With a factor of safety of 6, the working stress will be $\frac{2{,}415}{6} = 402$ lb. per sq. in., and to resist the given stress of 56,000 lb., it will require a cross-sectional area of $\frac{56{,}000}{402} =$ 139 sq. in. As the assumed breadth of the rafter is 12 in., the depth will be $\frac{139}{12} = 11.58$ in., or, using the next larger size in even inches, we have 12 in. × 12 in. for the size of the rafter.

The stress upon the straining beam *g h* is 42,800 lb., and its length, as measured on the center line of the beam, is 12 ft. 6 in. It will be at once apparent that with less stress and with less length than the rafter *c d*, the straining beam may be of smaller size and yet have the same factor of safety. It is customary, however, to make both rafter and straining beam of one size, as they form a better joint at the queen-rods and give an impression of greater strength. The

needle-beams *m* and *n* serve only as ties to hold the trusses in position. The cross-ties are laid directly upon the tie-beams, 16 in. from center to center. At 6,000 lb. per lineal foot, the uniformly distributed load upon each cross-tie is $6,000 \times 1.333 = 7,998$, say 8,000 lb., which is equivalent to a center load of 4,000 lb. With a factor of safety of 6, the center breaking load will be $4,000 \times 6 = 24,000$ lb. The distance between tie-beams is 12 ft. 10 in., say 13 ft. Assuming a breadth of 8 in. for the cross-ties, and denoting the required depth by x, we find the depth by applying the rule given in Art. **1807**, as follows:

$$24,000 = \frac{8 \times x^2}{13} \times 550,$$

whence, $x^2 = 70.90,$

and $x = 8.4$ in.

As we notch down the ties 1 in. on the tie-beams, we increase this depth to 9 in.

The queen-rods virtually divide the bridge span into three short spans of 12 feet each. We accordingly find the dimensions of the tie-beams for spans of that length. The load upon each tie-beam we assume at 3,000 pounds per lineal foot. The total uniformly distributed load on the tie-beam is, therefore, $3,000 \times 12 = 36,000$ lb., which is equivalent to a center load of $\frac{36,000}{2} = 18,000$ lb. With a factor of safety of 6, we have a breaking center load of $18,000 \times 6 = 108,000$ lb.

Assuming a breadth of 12 inches for the tie-beam, we find the depth by the rule given in Art. **1807.** Denoting the required depth in inches by x, we have

$$108,000 = \frac{12 \times x^2}{12} \times 550;$$

$$550\,x^2 = 108,000,$$

whence, $x^2 = 196.36$

and $x = 14$ in., the required depth of the tie-beam.

Besides the transverse stress upon the tie-beam, there is a

longitudinal pull $p\ q$, which amounts to 42,800 pounds. Allowing a working stress in tension of 3,000 pounds per square inch, it will require $\frac{42,800}{3,000} = 14.26$ square inches of area to resist this pull. We add this area to that already obtained for the tie-beam, being careful to make the increase in one dimension only, viz., the breadth. This gives us for the final dimensions of the tie-beam a breadth of say 13 inches and a depth of 14 inches.

The longitudinal stress in the rafter $c\ d$ develops a shearing stress along the grain at the foot of the rafter equal to the pull in the tie-beam, or 42,800 pounds.

Allowing a working stress for shear along the grain of 400 lb. per sq. in., it will require $\frac{42,800}{400} = 107$ sq. in. to resist this stress. The distance from the foot of the rafter to the end of the tie-beam is 12 in.; hence, the superficial area opposed to this shearing stress is $13 \times 12 = 156$ sq. in., which insures ample safety. The feet of the rafters are bolted to the tie-beams, thus preventing any lateral movement.

The needle-beams m and n serve two purposes, viz., as ties to hold the tie-beams in position, and as supports for the braces s, s which maintain the trusses in an upright position. These braces are fastened in place with boat spikes. The trusses are further braced by three sets of **X** braces t, t, as shown in the cross-section B. Each set has a length equal to one-third of the span. The ends of the braces are spiked to the tie-beams and bolted together at the point where they cross each other. On the inside of each tie-beam, directly over the bridge-seat, a groove is cut 1 in. in depth and 4 in. in breadth, to receive the spreader u, as shown in the detail. These spreaders are 4 in. $\times$ 12 in., and are held in place by the tie bolts v, v, which are 1 in. in diameter and fitted with cast washers. The effect of the rails is to distribute the loads concentrated upon the driving wheels of the locomotive over the entire wheel base, so that cross-ties which individually could not sustain these

concentrated loads are yet amply strong enough for their share of the distributed load. The trusses do not rest directly upon the bridge seats, but upon two 6 in. × 9 in. oak timbers *w*, *w*, which extend the full length of the bridge seat and distribute the weight of the bridge over the entire foundation.

The cast-iron shoulder block at head of rafters is shown in detail at *D*. The bridge seats are 2 ft. in breadth, and the abutments 3 ft. in thickness at the bridge seat. The faces of the abutments are vertical, while their backs have a batter of 1½ inches to the foot.

WATER STATIONS.

1815. Water stations are points along a railroad where the engines stop to take in water. Their distance apart will depend mainly upon the amount of the traffic, but somewhat upon the grades. On roads with a light traffic, water stations at intervals of 15 miles will meet every requirement, while roads with a heavy traffic and frequent trains may require them at every 5 or 6 miles.

They usually consist of large wooden tubs placed upon a strong framework, supported by heavy pillars which rest upon a foundation of masonry. The tubs are generally circular in form, the bottom diameter being a few inches larger than that of the top diameter, in order that the iron hoops may drive tight. White pine, cedar, and redwood are the varieties of timber principally used in the manufacture of tanks. The staves are planed by machinery specially designed to give them the proper bevel, so that when set up the joints are close and water-tight. The staves are fastened together at the top with a single dowel between each two, merely to hold them in place while being set up. The pieces forming the bottom of the tank are doweled together and fit into a groove about 1 inch in depth, which is cut into the staves to receive them. The hoops are fastened together with lugs which grip the two ends of the hoop. The two lugs are united by a bolt threaded at

both ends and fitted with nuts. By screwing up these nuts, a strain is put upon the hoop. The hoops are first nearly driven to place; the lugs are then tightened with a wrench, after which the driving is finished.

Railroad water tanks hold from 20,000 to 40,000 gallons. A common size is 16 ft. in diameter and 16 ft. in height, holding about 21,000 gallons. All tanks holding above 200 barrels are made from 3-in. stuff. This thickness is somewhat reduced by planing. The bottom of the tank should be from 10 to 12 ft. above the tops of the rails. It is a common practice to enclose the tank in a framed structure, the foundation and post supports forming the first story, and the tank, together with its covering, the second story. Where the supply of water is pumped, the first story is often used as a pump house, and a fire is usually maintained in winter to prevent the freezing of the water. At division or terminal points, where many engines are to be supplied, the tank is made proportionately larger, and often two are placed together.

It is desirable to combine a coaling with a water station, in order that an engine may take both fuel and water at the same time. Such an arrangement is usually made at division points and terminals, though it is not always practicable to place a water tank and coaling station side by side.

A tender of coal will serve for several tankfuls of water, so that coaling stations situated at division points, at intervals of say 100 miles, will serve every requirement.

When the railroad has a double track, it is customary to place a water tank on each side of the roadway, so that engines may take water from either track.

The tank house should stand near the track, leaving only from 2 to 4 feet clearance for cars.

1816. Source of Water Supply.—The least expensive and most satisfactory water supply is that obtained from either springs or brooks which have sufficient elevation to deliver water into the tank by gravity and so avoid the expense of pumping. Clear, pure water, as free as possible

from mineral matter in solution, is greatly to be desired. If the stream from which the supply is obtained is liable to become muddy from freshets, a reservoir of suitable size should be constructed and kept constantly full of clear water, so that, in case of a freshet, the flow of the water into the reservoir may be stopped until the stream runs clear.

Where spring water is used, and the supply in times of drouth is liable to run short, a reservoir of ample capacity should be constructed, and the surplus water stored for future use.

When the source of supply is too low to be delivered by force of gravity, resort is had to pumping. Formerly, horse-power was used to a considerable extent for pumping, but of late years steam and wind power have been exclusively employed. Pumping by wind mills is the least expensive, and, but for occasional calms, the most satisfactory. The only way to provide against a short supply due to calms is to make the capacity of the water tanks adequate for a number of days' supply. The tank has three pipes: an inlet pipe by which the water enters the tank, a waste pipe for preventing overflow, and a discharge, or feed-pipe, 7 or 8 inches in diameter, in or near the bottom, through which the water flows to the tender tank. The discharge pipe is from 8 to 10 feet long, and jointed at the end which joins the tank, so that when the tender tank is filled, the discharge pipe, acted upon by a counterweight, swings either sideways or vertically on its hinge joint, out of reach of the cars. The discharge pipe at its connection with the tank is provided with a valve which has a lifting gate. Movement is communicated to this gate by means of a lever, the short arm of which is attached to the valve rod. The long arm of the lever has a rope attached, which hangs within reach of the engineman.

When taking water, the discharge pipe is lowered and swung over the water hole in the tender tank. The engineman then pulls down on the lever. This action raises the valve stem and allows the water to flow from the water tank into the tender tank. Tender tanks hold from 2,500 to 3,500 gallons.

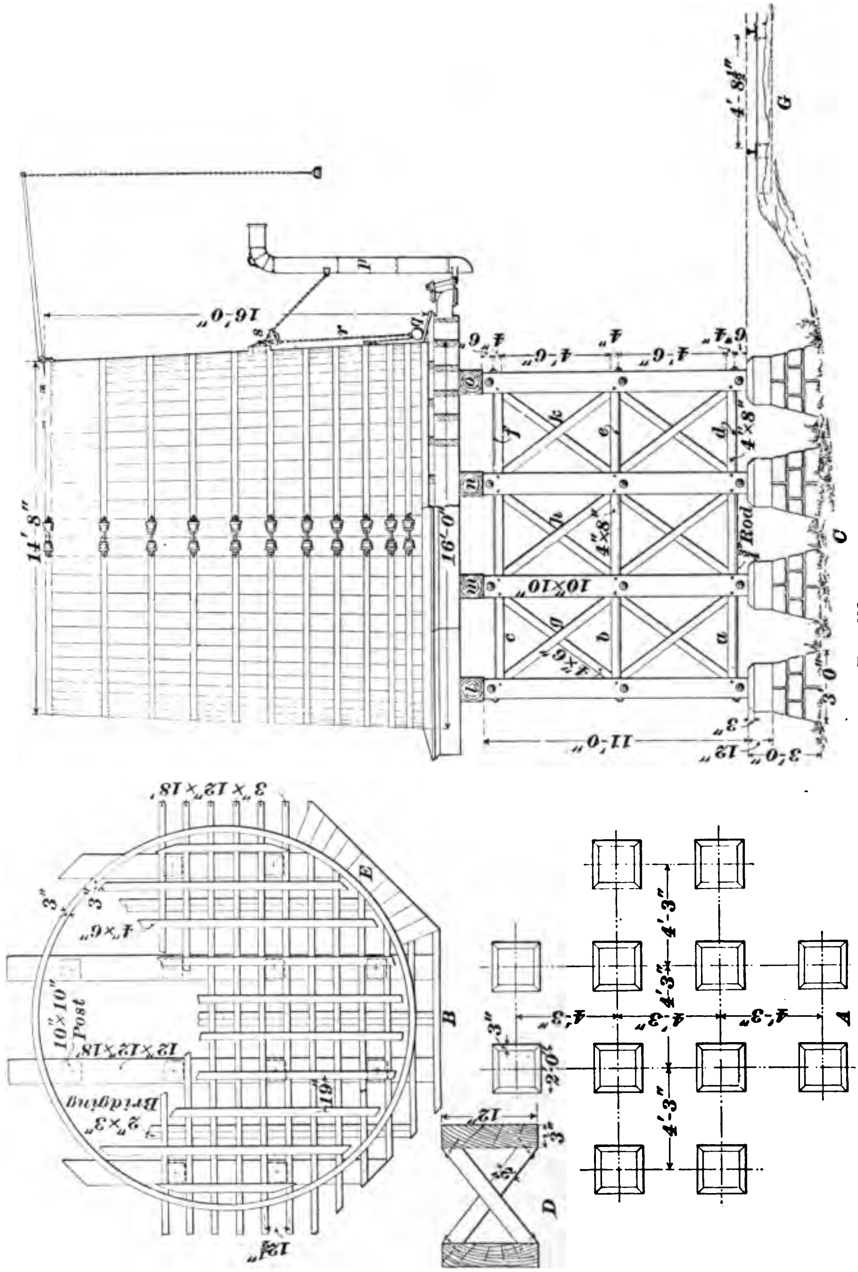

16'-0"
14'-8"
11'-0"
10"×10"
4"×8"
4"×6"
Rod
10"×10" Post
12"×12"×18'
3"×12"×18'
Bridging
2"×3"
4'-3"
4'-8½"
A
B
C
D
E
G

FIG. 632.

1817. Standard Water Tanks.—A general plan of a standard water tank is given in Fig. 632. The foundation is shown in plan at *A*; a plan of the arrangement of timbers composing the tank seat or deck is shown at *B*, and a complete elevation of the tank at *C*. The foundations should be of the most substantial character, of well-dressed stone laid in cement mortar. The foundation consists of either continuous walls laid at right angles, upon which the sills are placed and the posts mortised into them, or a pediment of pyramidal form is built for each post, as shown in the figure. Each post is secured to its pediment by a dowel 1 in. in diameter by 6 in. in length. The stone pediment forms a very substantial foundation. It is effective in appearance and does away with the sills, which are apt to decay from alternate wetting and drying.

The posts are connected together by girts *a*, *b*, *c*, which are tenoned into the posts and fastened with treenails. This connection is further strengthened by $\frac{3}{4}$ in. tie-rods *d*, *e*, *f*, which pass through each row of posts, a cast washer being placed under the head and nut of each tie-rod. Between each two rows of girts a series of X braces *g*, *h*, *k* is placed and securely spiked to the posts and girts. The caps *l*, *m*, *n*, *o*, upon which the beams which compose the deck rest, are 12 in. × 12 in., and fastened to the posts by mortise and tenon. The deck is composed of two sets of timbers laid at right angles to each other. The first set, laid directly upon the posts, are 3 in. × 12 in., and uniformly spaced. They are held together and strengthened by bridging (see detail *D*) besides being spiked to the caps. The second set of deck timbers are 4 in. × 6 in., and laid at right angles to the floor-beams. They are spaced 19 in. center to center, and extend to within 3 in. of the tank staves. They are in direct contact with the bottom of the tank, and receive the entire weight of the water contained in the tank without allowing any of its weight to rest upon the staves. The deck is usually made octagonal in form, and where the tank is not covered by a house, the deck is made to project far enough from the tank (as shown at *E*) to protect the foundation and timber

supports from the weather. The sides of the tank flare or batter outwards at the rate of $\frac{1}{2}$ in. to the foot, so that the hoops will drive tight.

The discharge pipe *p*, when not in use, takes the position shown in the figure, being held in that position by the weighted ball *q*, which is attached to the chain *r*, running through the sheave *s*, and thence to its connection with the discharge pipe. A cross-section of the track is shown at *G*, the top of the rail being 12 ft. below the outlet of the discharge pipe.

The valve connection of the discharge pipe with the tank is shown in Fig. 633. The connection may be made either

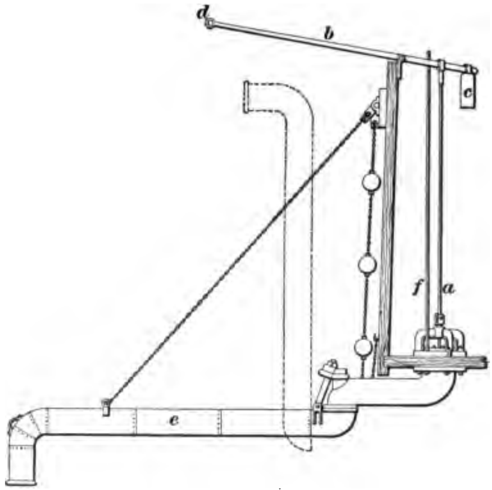


FIG. 633.

through the side or bottom of the tank. The bottom valve connection is shown in the figure. The valve rod *a* is attached to the short arm of the lever *b*. The weight *c*, attached to the end of the short arm of the lever, holds the valve firmly in place. A rope is attached to the end *d* of the long arm of the lever and hangs within reach of the engineman. By pulling down on this rope, the valve is raised, and the water flows through the discharge pipe *e* to the tender tank. The vacuum pipe *f* admits air to the discharge

pipe after the valve comes to its seat, so that the discharge pipe is quickly voided.

1818. Water Columns.—Where space is limited and the head of water is sufficient, a water column (see Fig. 634) is used in place of a tank. One advantage of a water column is in its economy of space, as will be at once apparent. It can safely be placed between the parallel tracks of a double-track road, and serve engines on both tracks equally well.

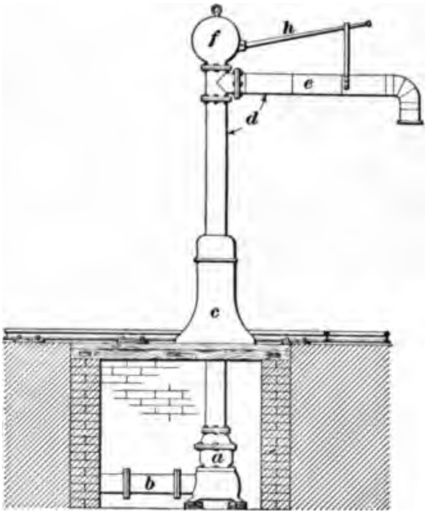


Fig. 634.

This water column consists of a globe valve *a*, connecting with the main water pipe *b*, and enclosed in a chamber of brick masonry. This chamber is covered with a substantial floor of timber, and forms the foundation for the pedestal *c*, which supports the crane-shaped water column *d*. This column is jointed at its connection with the pedestal, so that the discharge pipe may be readily swung over the tender when taking water. The cast-iron globe *f* (Fig. 635) is connected with the valve disk by means of the valve rod *g*, and by its weight keeps the

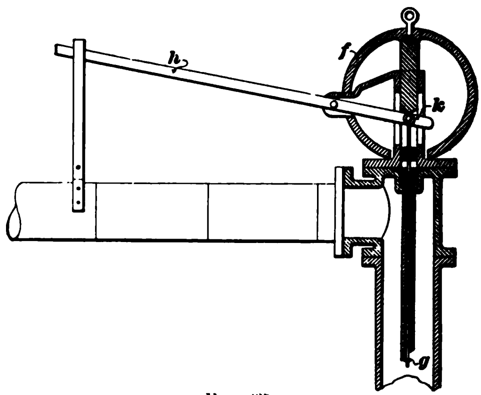


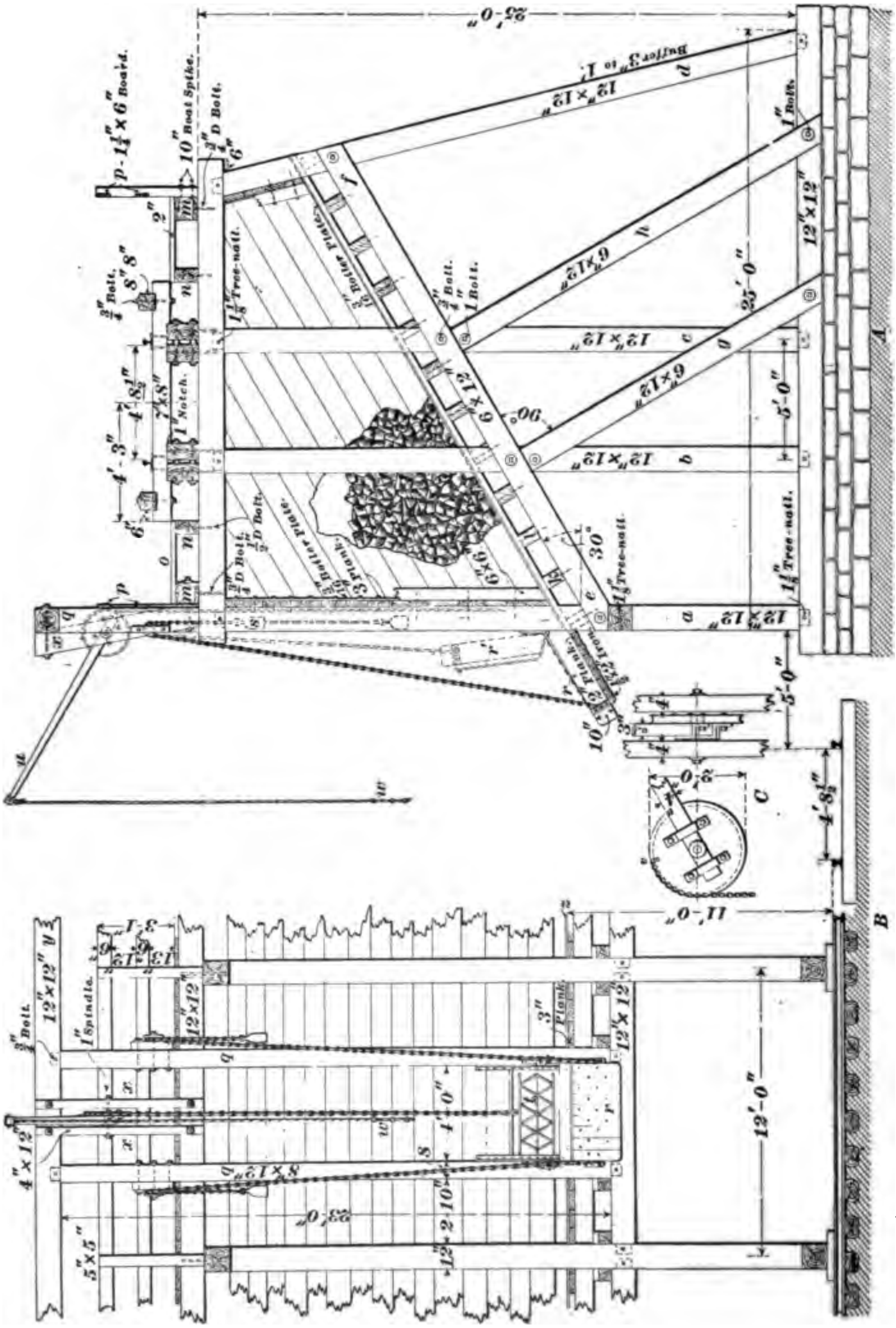
Fig. 635.

valve closed. When taking water, the lever *h* is depressed. This causes the short arm *k* of the lever to rise, and lifts the globe *f*. The weight being thus removed from the valve, the disk is lifted by the pressure of the water which flows through the discharge pipe to the tender tank.

COALING STATIONS.

1819. Coaling stations are points along a railroad where fuel is kept in stock for supplying locomotives. They are placed at all division points, large yards, and sometimes at the summits of long grades where pushers are employed. Formerly, many roads used wood as fuel, but coal, which is far more lasting and more economical of space, is now almost universally used. The coaling stations of thirty years ago were very primitive in design. The fuel was loaded by hand, the coal being loaded into small carts and dumped from a platform into the tender. A very decided advance in design was made when the coal pockets shown in Fig. 636 were introduced. The pockets are supported on bents of trestlework, each pocket comprising the space between two bents. The figure shows the cross-section at *A*, and the side elevation at *B*. Each bent is supported by four posts, *a*, *b*, *c*, and *d*. All are vertical except the last, *d*, which has a batter of 3 in. to the foot. Timbers *e f*, 6 in. × 12 in., are bolted to both sides of the posts and supported by batter posts *g*, *h*, also 6 in. × 12 in., which are bolted to both post and sill. These combined form the support to the pocket floor system, which consists of 6 in. × 10 in. floor-beams *k*, *l*, etc., laid 2 ft. center to center, as shown in the figure, and drift-bolted to the supports. Upon these floor-beams is laid a flooring of 3-in. oak planks, which are covered with plates of sheet iron from $\frac{1}{8}$ to $\frac{3}{16}$ in. in thickness to protect them from the wear of the coal.

The bents are spaced 12 feet, center to center, and planked on both sides above the floor with 3-in. planks, forming a series of pockets. This provides for storing coal



of different sizes, so as to meet the requirements of the different types of engines. The partition walls are also protected with sheet iron. The track stringers are placed directly over the middle posts. They consist of two pieces 8 in. × 16 in., and extend over two bents, as in ordinary trestle building. The ties are 7 in. × 8 in. × 10 ft., and notched down 1 in. on the stringers. They carry an 8-in. × 8-in. guard-rail, which is also notched 1 in. on the ties. Stringers are fastened to cap with drift-bolts, $\frac{3}{4}$ in. × 24 in., round iron. Stringers are spaced 3 in., and held in place by separators of cast iron. Stringer bolts are $\frac{3}{4}$ in. × 22 in. The bents are further tied together by the timbers *m*, *m*, 12 in. × 12 in., which are fastened to the caps with $\frac{3}{4}$-in. × 20-in. drift-bolts, and by the timbers *n*, *n*, 6 in. × 12 in., which partly support the plank walks *o*. These walks are protected by a railing *p p*, which is supported by posts spiked to the timbers *m*, *m*.

The coal is conducted from the pocket to tender by means of the spout or chute *r*, composed of planks and sheet iron. This chute, when in position for coaling a tender, is represented by *r*, and when not in use, by *r'*. It is fitted with counterweights *s*, somewhat heavier than itself, which enable the engineman to handle it with ease. The mouth of the pocket is closed by a sliding door *t*, of cast iron, which works in guides, and is operated by means of a lever *u*. This lever is attached to a grooved wheel, in which works a chain which is attached to the door *t*. The lever attachment is shown in detail at *C*. The chain is fastened to the groove of the wheel with a staple *v*. Power is applied to the lever by means of the rope *w*. The wheel is supported by two 4-in. × 12-in. oak timbers *x*, *x*, which are bolted to the plate *y* and the timber *m*. These are so fastened at the top as to project forward, as shown at *x* in the elevation. This throws the wheel axis forward, so that the lifting chain will clear the woodwork.

To take coal, the engineman first lowers the spout *r*; he then pulls down the lever *u* by means of the rope *w*, which raises the door *t* and allows the coal to run from the pocket

into the tender. The pocket floor at *z* should not be less than 11 ft. above the top of the rail.

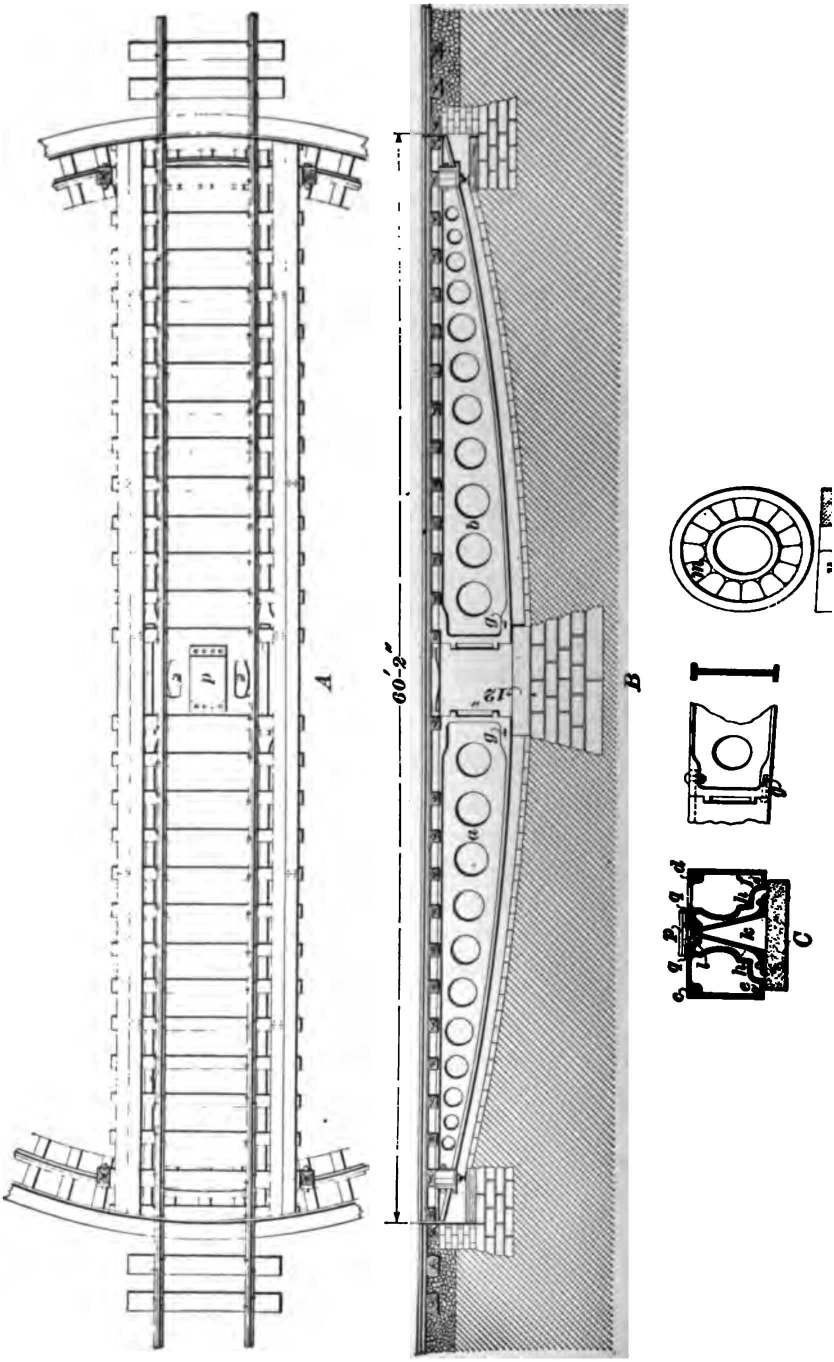
The loaded cars of coal are dumped directly from the track above into the pockets. The supply track is usually an incline plane, with a grade as sharp as is consistent with safe operation. Sometimes, where space is very limited, the loaded cars of coal are hauled to the top of the pockets by cable over a steep incline.

1820. A Modern Coaling Station.—A modern coaling station is shown in Fig. 637, in which the coal is handled by machinery. The figure includes a general plan of the station, the elevation being shown at *A* and the cross-section at *B*. The power to drive the machinery is furnished by the engine *c*. The machinery consists of an elevator *d d* and a conveyor *e e*, composed of link belts carrying projecting pieces of board, which, as they slide through troughs lined with sheet iron, form elevating or conveying buckets, first elevating the coal from the pocket beneath the track where it is dumped from the car, to the head of the incline, and then conveying it to the different pockets, where it is stored ready for the use of locomotives. The link belts are driven by sprocket wheels *f* and *g*. The power is transmitted from the engine to the machinery by means of a wire rope belt. The main sheaves *h* and *k* are 6 feet in diameter. They are attached to shafts carrying pinions which drive the gears *l* and *m*, and with them the sprocket wheels *f* and *g*. The coal to be elevated to the coal pockets is first dumped from the car *n* into a chamber beneath the track. The coal runs by gravity from this chamber through the opening *o* into the elevating chute *p*, which is lined with sheet iron, and as the projecting boards carried by the link belt pass under the sprocket wheel *q*, they push the coal before them, forming a series of buckets, which carry the coal to the point *r*, where an opening in the chute allows the coal to fall into the conveying chute *s*. Here a similar series of buckets, passing around the sprocket wheel *t*, collects the coal as it falls from the elevator chute and carries it to the storage

pockets of the station. In the bottom of the conveying chute, and directly above each pocket, is an opening of suitable dimensions. These openings are fitted with sliding covers, which are close fitting, and all of them are closed excepting the one connecting with the pocket to be filled. The sheave *u* is fitted with a sliding journal which provides for taking up any slack in the wire rope drive due to stretching. The link belt of the elevator on its return is supported by the sheaves *v* and *w*, and the conveyor belt by the sheave *x*. These sheaves are supported by brackets bolted to the floor timbers of the chutes. The pockets are enclosed with planks and covered by a slate roof, an open space 2 feet in width being left under the eaves for the free circulation of air. The general form of the coal pockets is the same as those shown in Fig. 636. The coaling spouts *y*, *y* are made of cast iron, instead of plank lined with sheet iron. The spouts are raised and lowered by means of counterweights, as shown both in elevation and cross-section. The pockets are lined with sheet iron or steel. The gauge line of the track is commonly placed 5 ft. from the face of the coal pockets, and the bottom of the pockets at their connection with the spouts 12 ft. above the rail.

TURNTABLES.

1821. A turntable, as shown in Fig. 638, is a platform usually from 50 to 70 feet long, and from 8 to 10 feet wide, upon which a locomotive and tender may be run and then turned horizontally through any portion of a circle, and thus be transferred from one track to another forming any angle with it. The table is supported by a pivot under its center, and by wheels or rollers under its ends. Beneath the platform is excavated a circular pit 4 or 5 feet deep, having its circumference lined with brick or stone masonry 2 feet in depth, and capped with either cut stone or wood. The diameter of the pit in the clear is about 2 inches greater than the length of the turntable. The masonry lining is usually built with a step (see elevation *B*), which supports


A
B
C
60'-2"

the rail upon which the end rollers travel. At the center of the pit is a substantial foundation of masonry, upon which the pivot rests. This foundation should be 4 or 5 feet in depth and composed of large, regularly shaped stones laid in cement mortar and well bonded together. This foundation is capped by a single stone 6 ft. square and 12 in. in thickness. The pivot, shown in detail at *C*, is fastened to the foundation by heavy anchor bolts reaching the full depth of the masonry. Sometimes the pit is floored over with plank, but this so greatly increases the weight of the table, besides involving the expense of renewal, that it should be dispensed with unless circumstances make a floor necessary. Usually, only a walk of planks, supported by the projecting ties, is allowed.

The turntable should be somewhat longer than the total length of both locomotive and tender, so as to permit the engineman to move his engine a few feet in either direction from the pivot in order to secure an equilibrium. With a little practice, such an equilibrium is easily obtained. By this means the friction while turning is confined chiefly to the center of motion.

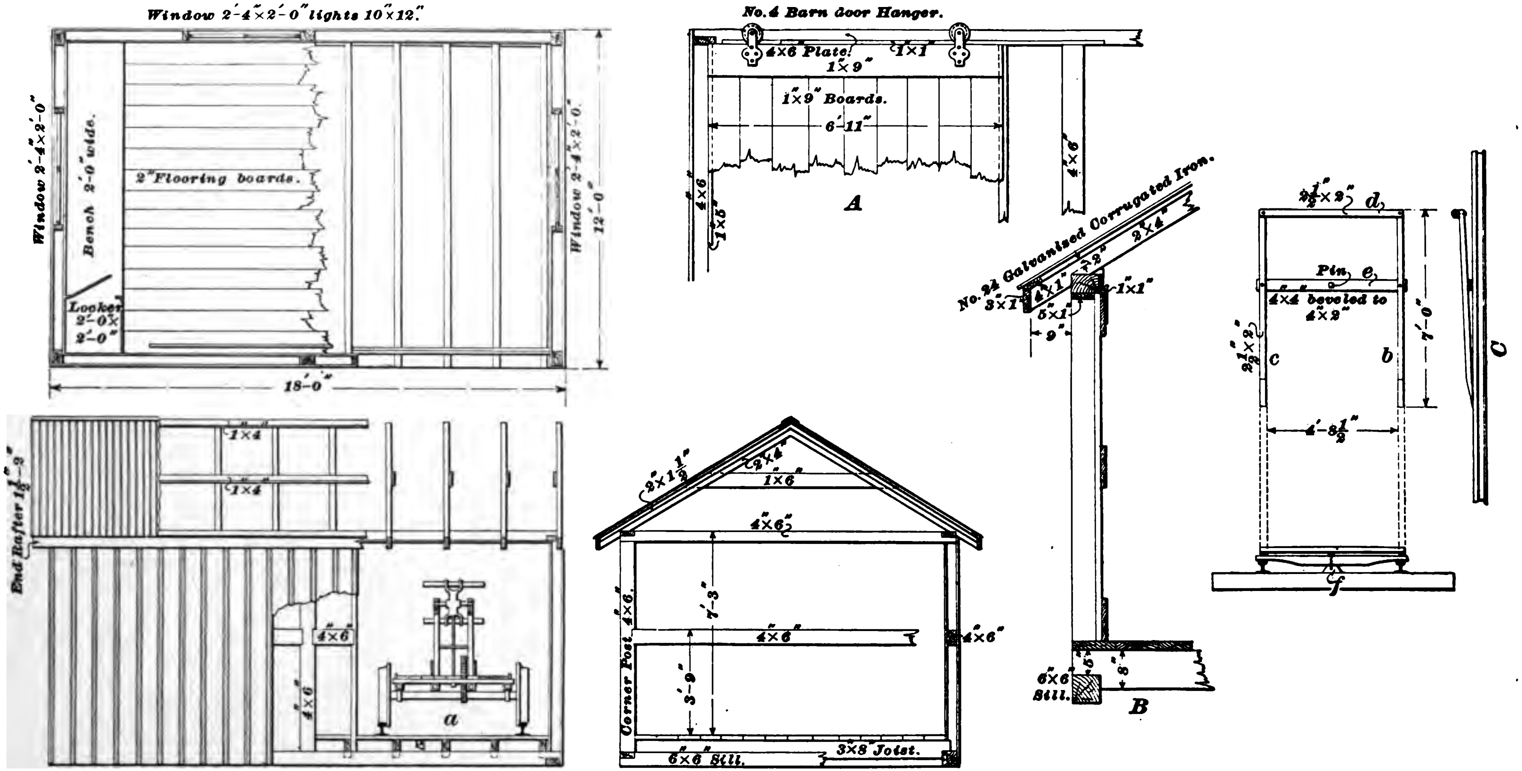
Probably the best turntables in use in America are manufactured by Wm. Sellers & Co., of Philadelphia, Pa. The turntable shown in Fig. 638 is a copy of their recent standard. They are expensive in first cost, but most economical both in operation and in the matter of repairs. Being composed chiefly of metal they are very enduring, and as the parts are readily duplicated, repairs are simple and expeditious. One man can readily turn one of these tables, loaded, without the assistance of machinery. They consist of two heavy cast-iron girders, perforated by circular holes to reduce weight and cost. Each girder consists of two parts, *a* and *b*, fastened to a heavy central boxing, shown in cross-section at *C*.

The girders are fastened to it by means of heavy iron bars *c*, *d*, $3\frac{3}{4}$ in. square, of rolled iron, fitted into sunk recesses on top of the boxing, and tightened in place by

means of wedges, and also by means of two 2¼-in. key bolts at the base of the girders, passing through the holes *e*, *f*, and confined by the keys *g*, *g*. The central portion of the boxing is a hollow cone *h*, open at top and bottom, and surrounding the hollow conical pivot post *k*. The pivot shell is about 1¾ in. thick. On top of the post rests a heavy, loose, cast-iron cap *l*, which permits of a slight rocking motion of the entire platform as the engine enters and leaves the turntable. This cap supports the steel box (see detail *D*) containing the **friction rollers** *m*. There are fifteen of them, each about 2¾ in., both in length and greatest diameter. They have no axles, but lie loosely in the lower part of the box, filling its circumference, save a half-inch of space left for the free movement of the rollers. In the direction of their axis they have but ⅛ in. play in the box. The lid *n* of the box rests directly upon the rollers themselves, and does not come down to the lower part *o* of the box by ½ inch. Both the rollers and the box enclosing them are finished with mathematical accuracy, so as to ensure a perfect bearing between them. The rollers are kept constantly oiled, as ease in turning depends entirely upon their being well lubricated. On top of the rollers is the cap *p*, which is secured by heavy bolts. This cap does not rest directly upon the boxing, but is separated from it by wooden wedges *q*, *q*, by means of which the table may be raised or lowered and its height exactly adjusted to the connecting track.

When the engine is properly balanced, the cap bolts sustain all the load placed upon the turntable, excepting the small amount carried by the tracks at the end of the platform.

When properly balanced on a Sellers' turntable, the end wheels should only just touch the rails. The diameter of the roller box being 15 in., it is not difficult to balance the locomotive and tender. All turntables should be provided with the means of being raised or lowered, and so adjusted as to give the proper bearing upon the circular track.



Window 2'-4"×2'-0" lights 10"×12."
Window 2'-4"×2'-0"
Bench 2'-0" wide.
2" Flooring boards.
Locker 2'-0"× 2'-0"
Window 2'-4"×2'-0".
12'-0"
18'-0"
1×4
1×4
End Rafter 1$\frac{1}{2}$"-2"
4"×6"
4"×6"
a
No.4 Barn door Hanger.
4×6 Plate.
1×1
1"×9"
1"×9" Boards.
6'-11"
4"×6"
4"×6"
1×5
A
No. 24 Galvanized Corrugated Iron.
2"×4"
3"×1"
4×1"
5×1
1×1"
9"
6"×6" Sill.
5"
8"
B
2$\frac{1}{2}$"×2"
d
Pin
e
4"×4" beveled to 4"×2"
2$\frac{1}{2}$"×2"
c
b
7'-0"
4'-8$\frac{1}{2}$"
f
C
2"×1$\frac{1}{2}$"
2"×4"
1×6
4"×6"
7'-3"
4"×6"
3'-9"
Corner Post 4"×6.
4"×6"
6"×6" Sill.
3"×8" Joist.

FIG. 629.

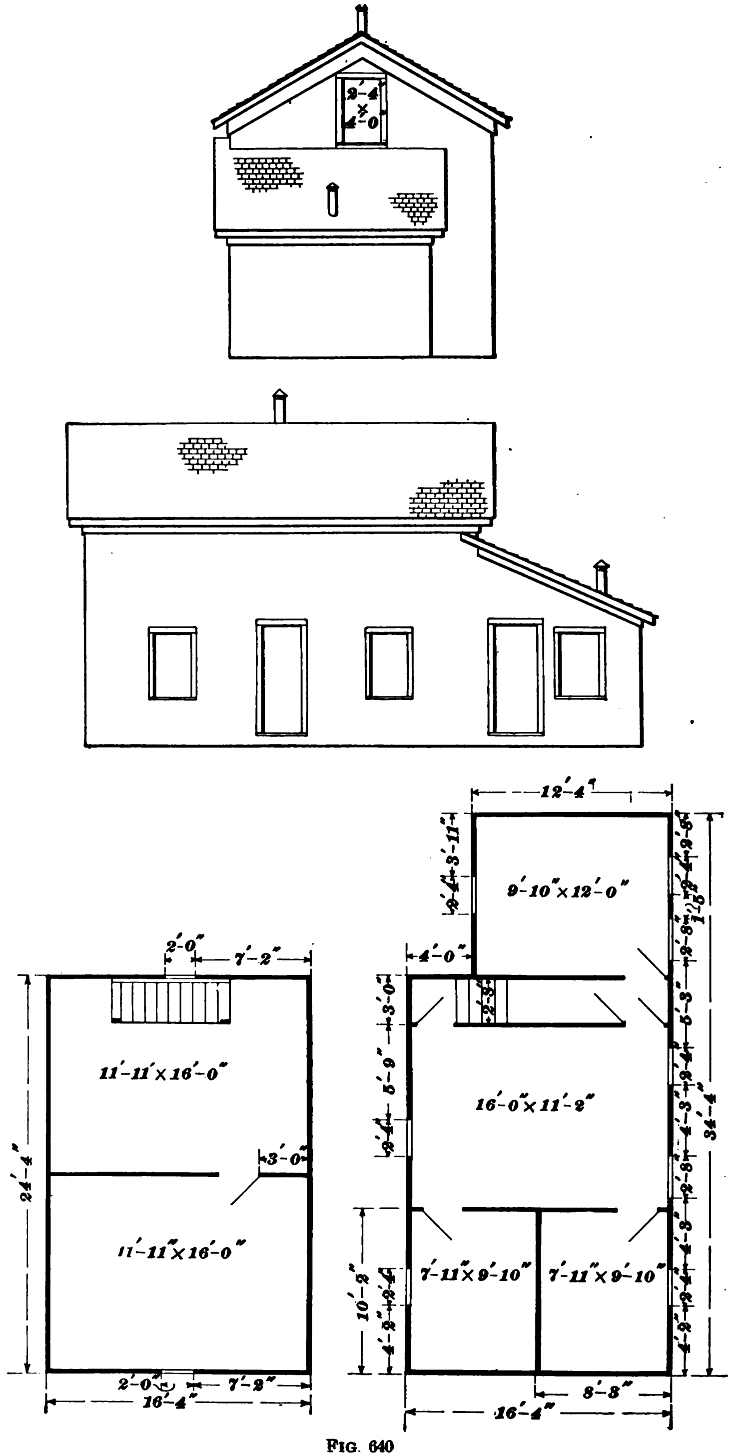
SECTION BUILDINGS.

1822. Tool Houses.—At the headquarters of each section a tool house is erected for the storage of hand and push cars, track tools, and all track materials which may be damaged by exposure to the weather, or, on account of their portability, likely to be stolen. Among the latter class are track bolts and track spikes, nails and cut spikes, shim and pin timber, etc. The tool house should not connect directly with the main track, but with a siding, so that a train standing on the main track will not interfere with a crew starting for work with either hand or push car. The tool house should be placed convenient to that occupied by the section foreman, so that all tools and material may be near his hand either for repair or inspection, or for use in case of an emergency. All tools and material contained in the house should be kept in perfect order and repair. A building fully meeting the requirements of a tool house is shown in Fig. 639. It should rest upon a substantial foundation of masonry, and stand fully 12 inches above the surface of the ground, so as to allow ample circulation of air among the floor timbers. At one end of the house is a work bench fitted with a vise, together with wrenches, hammers, hand saws, punches, and any other tools necessary in making repairs of tools or track.

The hand and push cars rest upon a permanent track, shown at *a*. They are admitted through a sliding door shown in detail at *A*.

A device for transferring the hand car to the tool house track is shown at *C*. It consists of two oak pieces *b* and *c* which serve as rails. They are held at gauge by the cross-piece *d* and the bolster *e*, which are bolted to the strips. A pin passes through the bolster *e* into a socket in the cast-iron portable pedestal *f* on which the frame revolves. In using, the pedestal is placed upon a tie with the pieces *c*, *d* lying directly upon the rails. The hand car is then run upon the frame, which is revolved so as to connect with the tool house track.

The tool house should be well provided with racks, upon which the various tools of the section may be safely and



2'-4" × 4'-0"
12'-4"
9'-10" × 12'-0"
2'-0"
7'-2"
4'-0"
11'-11' × 16'-0"
16'-0" × 11'-2"
3'-0"
24'-4"
34'-4"
11'-11" × 16'-0"
7'-11" × 9'-10"
7'-11" × 9'-10"
10'-3"
2'-0"
7'-2"
16'-4"
8'-3"
16'-4"

FIG. 640

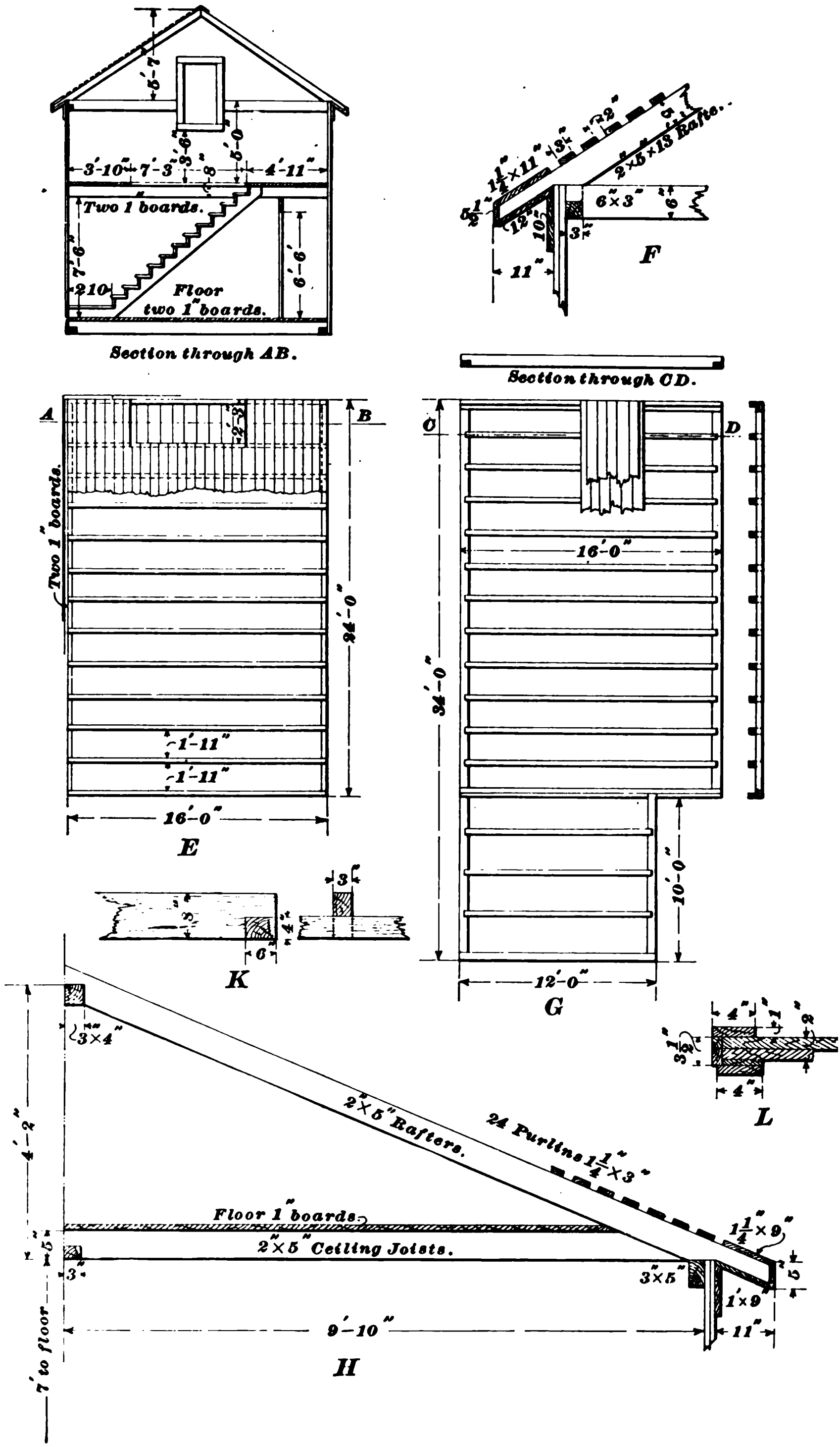
economically stored. Hooks of iron or of wood nailed to the sides of the house are especially handy for hanging up shovels. A locker built under the work bench is useful for storing lanterns and oil cans.

The plan shown is in detail, so that it may be used as a guide for any who wish to build a safe and economical tool house. A section through the door is shown in detail at *B*. The roof covering is of corrugated iron, which also serves as a protection against fire.

1823. Section Dwelling Houses.—Dwelling houses for section men should be substantial, neat, and of moderate size and cost. A house meeting these requirements is shown in Figs. 640 and 641. It has a balloon frame, is strong, and may be undertaken and built by any carpenter of average intelligence. It provides ample accommodation for a family of eight persons, and will contain twelve with but little crowding. The outer walls and partitions consist of two courses of inch boards nailed vertically to the frame. They should be surfaced on one side, ship lapped, and well seasoned before being put in place. This gives a smooth surface on both sides of the walls, and takes paint well.

Door and window casings should be of pine. The ground floor is of material similar to the walls, excepting that the floor boards should be tongued and grooved. Complete framing plans are shown, and will serve as a guide to those undertaking similar work. The cross-section *A B* shows the arrangement of the stairs and spacing of floors. A framing plan of the second floor is shown at *E*, and of the first or ground floor at *G*. A detail of the roof frame of the main body of the house is shown at *F*, and of the roof of the addition at *H*. A detail of the sill and floor joist is shown at *K*, and of a door casing at *L*. The roof covering, like that of the tool house, should be of corrugated iron.

1824. Watchman's Shanty.—A watchman's shanty should be large enough to comfortably accommodate one man, no more. This will include space for a stove for warming



Two 1" boards.
Floor two 1" boards.
Section through AB.
1¼ × 11"
2 × 5 × 13 Rafts.
6" × 3"
F
Section through CD.
A
B
C
D
Two 1" boards.
1'-11"
24'-0"
16'-0"
E
10'-0"
12'-0"
G
K
L
3 × 4"
2" × 5" Rafters.
24 Purlins 1¼" × 3"
Floor 1" boards
2" × 5" Ceiling Joists.
3" × 5"
1¼" × 9"
1" × 9"
9'-10"
11"
4'-2"
7' to floor
H

Fig. 641.

the building in winter. A general plan for a watchman's

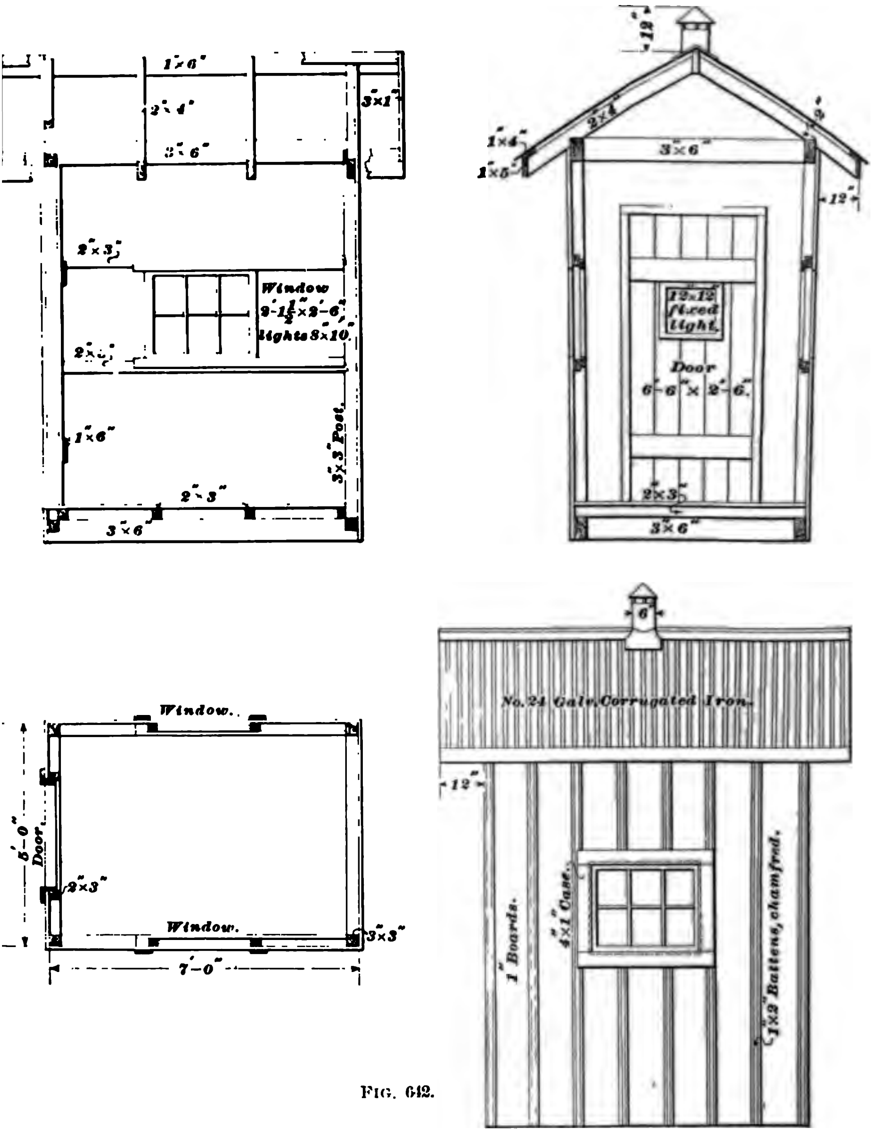


FIG. 642.

shanty is given in Fig. 642, which is sufficiently detailed for practical use.

(624) What is meant by similar polygons? Give examples.

(625) One of the angles of a triangle is 30°; one of the including sides 5 inches, and the difference of the other two sides 1.5 inches; construct the triangle.

(626) How is the north end of the magnetic needle determined?

(627) How is the compass circle divided, and how are the degrees numbered?

(628) Explain why the east and west points of the compass plate are marked the reverse of their natural order.

(629) What are the principal defects of the compass?

(630) What constitutes a *course?*

(631) How is the bearing of a line taken and how checked?

(632) How is a line run by backsights?

(633) Define local attraction and state by what it is usually caused.

(634) Explain the difference between the magnetic meridian and a true meridian.

(635) What is meant by the declination of the needle?

(636) How is a true meridian established?

(637) Explain the difference between a magnetic bearing and a true bearing.

(638) (*a*) The declination is 3° 15′ east; what are the true bearings of the following lines, their magnetic bearings being:

Magnetic Bearing.	True Bearing.
N 15° 20′ E	
N 88° 50′ E	
N 20° 40′ W	
N 50° 20′ E	

(*b*) The declination is 5° 10′ west; required, the true bearing of the following lines:

Magnetic Bearing.	True Bearing.
N 7° 20′ W	
N 45° 00′ E	
S 15° 20′ E	
S 2° 30′ W	

(639) How are stations in railroad surveys numbered, and what is the interval between stations?

(640) What are the special advantages which the compass offers in preliminary railroad surveys, and what conditions should determine its rejection for such work?

(641) Describe the process of chaining.

(642) Plat the following compass notes:

Station.	Bearing.
60 + 20	
50 + 90	N 80° 15′ E
44 + 50	S 45° 55′ E
28 + 13	S 11° 25′ E
20 + 11	S 76° 30′ E
10 + 89	N 79° 25′ E
5 + 20	N 40° 50′ E
0	N 10° 10′ E

(643) Describe the vernier. A vernier is described as reading to single minutes. Make a drawing of such a vernier and explain its use.

(644) Explain the different adjustments.

(645) How is a line prolonged by backsight? by foresight?

(646) Explain by figure the process of double centering, and state its advantages.

(647) Define a horizontal angle and its measurement.

(648) Of what value is the magnetic needle where all angles are read with the vernier?

(649) Explain by example what is meant by calculated or deduced bearings.

(650) The magnetic bearing of a line is N 55° 15′ E, and an angle of 15° 17′ is turned to the right; what is the bearing of the second line?

(651) The magnetic bearing of a line is N 80° 11′ E, and an angle of 22° 13′ is turned to the right; what is the bearing of the second line?

(652) The magnetic bearing of a line is N 13° 15′ W, and an angle of 40° 20′ is turned to the left; what is the bearing of the second line?

(653)

Station.	Deflection.	Mag. Bearing.	Ded. Bearing.
54 + 25			
49 + 20	L. 25° 14′	S 25° 40′ W	
44 + 80	L. 10° 47′	S 50° 50′ W	
33 + 77	R. 16° 55′	S 61° 45′ W	
25 + 60	R. 24° 40′	S 44° 50′ W	
16 + 20	L. 15° 35′	S 20° 00′ W	
8 + 90	R. 10° 15′	S 35° 50′ W	
4 + 40	R. 15° 10′	S 25° 20′ W	
0		S 10° 15′ W	

Calculate the bearings of the foregoing transit notes of an angle line and plat them to a scale of 400 feet to the inch, showing the direction of the magnetic meridian.

(654) The line of survey $A B$ (see Fig. 12) crosses a stream C D too wide for direct measurement. The angle A is 80° 20′, the angle E is 60° 15′, the side $A E$ is 415 feet; required, the angle B and the side $A B$.

Ans. $\begin{cases} \text{Angle } B = 39° \ 25'. \\ \text{Side } A B = 567.44 \text{ ft.} \end{cases}$

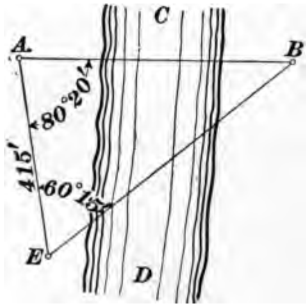


FIG. 12.

(655) An obstacle, Fig. 13, lies in the path of survey A B. Show how the equilateral triangle may be used in passing the object and prolonging the line of survey.

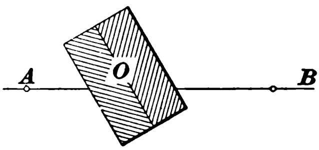


FIG. 13.

(656) What is an intersection of tangents? How is it made and the angle of intersection measured?

(657) Define *curve* and *tangent* as applied to railroad engineering.

(658) Name and describe the three classes of curves used in railroad building.

(659) What is the amount of the divergence of two lines 100 feet in length and forming an angle of 1° with each other?

(660) What is the unit curve employed in railroad building? Define it.

(661) Define a five-degree (5°) curve.

(662) What is the ratio of the degree of curve to the deflection angle for a chord of 100 feet?

(663) What is the formula for finding the *radius*, the deflection angle being given?

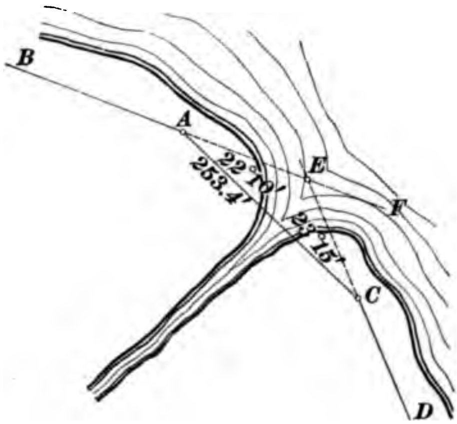


FIG. 14.

(664) What is the formula for finding the length of any chord, the radius and deflection angle being given?

(665) What is the tangent distance, and what formula is used in finding it?

(666) The tangents $A B$ and $C D$, in Fig. 14, intersect at some inaccessible point E. The angle A is 22° 10′, the angle C 23° 15′, and the side $A C$ 253.4 feet; required the angle of intersection $C E F$, and the sides $A E$ and $E C$.

Ans. { Angle $CEF = 45° 25'$. Side $A E = 140.44$ ft., nearly. Side $C E = 134.24$ ft., nearly.

(667) The angle of intersection of two tangents is 35° 10′; the degree of curve is 6° 15′; what is the tangent distance? Ans. 290.66 ft., nearly.

(668) The angle of intersection is 14° 12′; the degree of curve, 3° 15′; what is the tangent distance? Ans. 219.62 feet.

(669) How is the length of curve found?

(670) The angle of intersection is 30° 45′; the degree of curve, 5° 15′; what is the length of the curve? Ans. 585.71 feet.

(671) The angle of intersection is 33° 06′; the station of the point of intersection, 20 + 37.8; the degree of curve, 5°; what is the station of the P. C., length of curve and station of the P. T.?

Ans. { P. C. = 16 + 97.17. Length of curve = 662 ft. P. T. = 23 + 59.17.

(672) The angle of intersection is 20° 10′; the tangent distance, 291.16 feet; required, the radius and degree of curve.

Ans. { Radius = 1,637.29 feet.
Degree of curve, 3° 30′.

(673) What is the formula for the chord deflection?

(674) What is the ratio of the chord deflection to the tangent deflection?

(675) The degree of curve is 7°; what is the deflection angle for a chord of 48.2 feet? Ans. 1° 41.22′.

(676) The degree of curve is 6° 15′; what is the deflection angle for a chord of 72.7 feet? Ans. 2° 16.3′.

(677) The degree of curve is 5° 30′; what is the tangent deflection, or offset, for 50 feet? Ans. 1.199 feet.

(678) The degree of curve is 4° 15′; what is the chord deflection for 35.2 feet? Ans. 0.919 foot.

(679) What is the radius of a 3° 10′ curve?

Ans. 1,809.57 feet.

(680) Two lines of equal length forming an angle of 1° with each other diverge 18.22 feet; what are the lengths of the lines?

Ans. { By trigonometry, 1,043.53 feet.
By practical method, 1,044.13 feet.

(681) A curve is 606.25 feet in length; the angle of intersection is 24° 15′; what is the degree of the curve?

Ans. 4°.

(682) What are the different processes of leveling? Define them.

(683) Describe the **Y** level and explain its adjustments.

(684) The level rod is held 300 feet from the instrument; the reading is 6.81 feet. After causing the level bubble to move over one division of the scale, the reading is 6.84; what is the radius of the bubble tube? Ans. 100 feet.

(685) What is meant by the *power* and *definition* of a telescope?

(686) Describe the self-reading leveling rod.

(687) The elevation of the point where the backsight is taken is 61.84 feet, the backsight is 11.81 feet, and the foresight to a turning point (T. P.) is 0.49 foot; what is the elevation of the T. P.? Ans. 73.16 feet.

(688) Define a datum line.

(689) What are turning points?

(690) What are bench marks?

(691) What are the principal sources of error in taking levels?

(692) Explain the process of checking level notes.

(693) What is a profile?

(694) Define a 1 per cent. grade.

(695) The elevation of the grade at Station 66 is 126.50; between Stations 66 and 100 there is an ascending grade of 1.25 per cent.; what is the elevation of the grade at Station 93? Ans. 160.25 feet.

(696) What is topographical surveying?

(697) The elevation of a station is 56.5 feet; the ground on the left falls 10.3 feet in a distance of 73 feet, where the slope changes, giving a fall of 16.4 feet in a distance of 56 feet. On the right the ground rises 11.4 feet in a distance of 84 feet, where the slope changes, giving a rise of 8.8 feet in a distance of 96 feet. How are these slopes recorded in the topographer's book? How many 10-foot contours are included by the side slopes, and what are their elevations, the contours being placed at even decimal intervals of 10 feet? What are the several distances of the contours from the center line?

(698) Work out the elevation of the following notes; check the notes, plat them in a profile, and draw a descending grade line of 80 feet to the mile, and place in the

column headed Grade the elevation of the grade of each station given in the station column:

Station.	Rod Reading.	Ht. Instrument.	Elevation.	Grade.	Remarks.
B. M. + 5.53			161.42		B. M. on Poplar tree 10 ft. left; Sta. 40.
40	6.4			162.0	
41	7.2				
41 + 60	10.9				
42	8.6				
43	8.8				
T. P. −	8.66				
+	2.22				
44	4.8				
45	6.3				
46	8.8				
47	9.9				
48	11.1				
T. P. −	11.24				
+	3.30				
49	4.7				
50	7.1				
51	8.7				
52	9.8				
53	10.9				
T. P. −	11.62				

(699) The ground to the right of the center line has an ascending slope of 11° for a distance of 120 feet, and to

the left of the center line a descending slope of 9° for a distance of 117 feet, where the slope changes to a descending slope of 5 for a distance of 65 feet; how are the slopes recorded in the topographer's book? If the elevation of the ground at the center line is 75.0 feet, how many 5-foot contours are included by the given slopes, and what are their respective distances from the center line?

(700) The angle of slope is 3°; what is the horizontal distance for a rise of 10 feet?

(701) An instrument is stationed at *A*, Fig. 15, 100 feet from the base of a church spire *B C*. The horizontal line

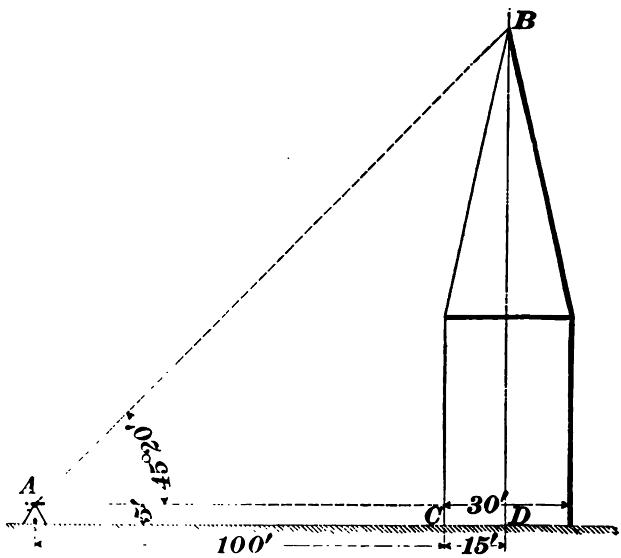


FIG. 15.

of sight *A C* from the instrument is 5 feet above the base of the spire, which at that point is 30 feet in diameter. The angle *C A B* is 45° 20'; required, the height of the spire. Ans. 121.345 feet.

(702) The height of barometer *h* at lower station is

29.40 in.; the temperature $t = 74°$; the height of barometer H at the higher station is 26.95 in., and the temperature $t' = 58°$; what is the difference in elevation?

Ans. 2,454 feet.

(703) What is hydrographic surveying?

(704) What stage of tide is the basis for all soundings?

(705) What is a tide gauge?

LAND SURVEYING.

(ARTS. 1309–1344.)

(706) What are the names of the general divisions into which the public lands of the United States are divided?

(707) Give the dimensions and contents of each.

(708) (*a*) Define a *Principal Meridian*. (*b*) How is it established? (*c*) What boundaries are marked on it?

(709) What causes *convergency* of *meridians*, and what effect does such convergency have upon the boundary lines of the Government surveys?

(710) (*a*) What are *Standard Parallels?* (*b*) What is their object? (*c*) What boundaries are marked on them?

(711) How are townships described with reference to *Base Line* and *Principal Meridian?* Illustrate by a diagram.

(712) Show by a diagram how township lines are run and the order of the survey.

(713) Explain by figure the terms *random line* and *true line*.

(714) How are excesses or deficiencies of measurement disposed of in townshiping and sectioning?

(715) Show by a diagram the subdivisions of townships and the order of survey.

(716) (*a*) Define *meandering* as applied to Government surveys. (*b*) In mapping, what use is made of meander lines? (*c*) How are islands located?

(717) What is a *line tree*, how is it marked, and how are trees on either side of the line of survey marked?

(718) How is a boundary corner in a timbered country marked?

(719) Describe the *township* corner-post or corner-stone. How is it set, and how marked?

(720) Describe a *section* corner, and explain how it is set and marked.

(721) How are *mound* corners constructed?

(722) What are *double corners*, where are they found, and how are they designated?

(723) In running township and section lines, what account should the surveyor take of the topography of the country?

(724) What are the various field books used in the survey of Government lands?

(725) State why the retracing of *old lines* or original surveys is so difficult.

(726) Suppose the original notes of a farm survey are the following, and suppose that only two of the original corners, viz., *B* and *C*, remain, and that we find the present bearing from *B* to *C* is N 60° 15′ E, how may we determine the magnetic variation, and what will be the corrected bearings by which we may restore the original boundaries?

Stations.	Bearings.	Distances.
A	N $31\frac{1}{2}$° W	10.4 chains.
B	N 62° E	9.2 chains.
C	S 36 E	7.6 chains.
D	S $45\frac{1}{2}$° W	10.0 chains.

(727) How are boundary lines straightened and new corners established where old ones are obliterated?

(728) What are witness trees, and how are they marked?

(729) Explain by a figure the triangular method of calculating areas.

(730) Explain by a figure the trapezoidal method of calculating areas.

(731) Define (*a*) the latitude of a point; (*b*) the longi-

tude of a point; (*c*) the latitude of a line, and (*d*) the departure of a line.

(732) The line *A B*, in Fig. 16, has a bearing of N 30° E and a length of 187 ft. Complete the figure, showing the latitude and departure of *A B*, and calculate their respective lengths by means of a table of sines and cosines.

(733) Describe a *traverse table*.

(734) The bearing of a line is N $23\frac{1}{4}$° E; its length is 423 ft.; calculate its latitude and departure by the use of a traverse table, and explain the process.

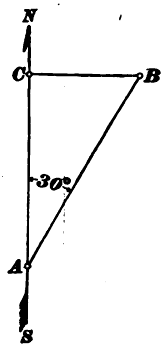


FIG. 16.

(735) The length of a line is 225 ft.; its bearing is 40°; what are the latitude and departure of the line, and what is the relation of that latitude and departure to the latitude and departure of the complement of the given bearing?

(736) How are latitudes and departures applied in testing the accuracy of a survey?

(737)

Stations.	Bearings.	Distances.
1	N $31\frac{1}{2}$° W	10.40 chains.
2	N 62° E	9.20 chains.
3	S 36° E	7.60 chains.
4	S $45\frac{1}{2}$° W	10.00 chains.

Calculate the latitudes and departures of the courses in the accompanying example, and balance them, giving all the steps of the process.

(738) Calculate the total latitudes and departures from Station 2, and from them make a plat of the survey explaining the different steps in the process.

(739) What is the *longitude* of a line?

(740) What is the general rule for the *double longitude* of any course of a given survey?

(741) Illustrate by a figure the method of computing areas by double longitudes.

(742) What are *north products* and what *south products*?

(743) If the double longitude is negative and the corresponding latitude positive, is the product *north* or *south?*

(744) How is the most easterly or most westerly station of a survey found?

(745)

Stations.	Bearings.	Distances.
1	S 21° W	12.41 chains.
2	N 83¼ E	5.86 chains.
3	N 12° E	8.25 chains.
4	N 47° W	4.24 chains.

Find the area by double longitudes, giving all the intermediate steps.

Ans. 4 A. 2 R. 35.8 P.

(746)

Stations.	Bearings.	Distances.
1	S 21¼ W	17.62 chains.
2	S 34° W	10.00 chains.
3	N 56° W	14.15 chains.
4	N 34° E	9.76 chains.
5	N 67 E	2.30 chains.
6	N 23° E	7.03 chains.
7	N 18½° E	4.43 chains.
8	S 76½° E	12.41 chains.

Find area by double longitudes.

Ans. 33 A. 0 R. 8.8 P.

(747)

Stations.	Bearings.	Distances.
1	N 18¾° E	1.93 chains.
2	N 9° W	1.29 chains.
3	N 14° W	2.71 chains.
4	N 74° E	0.95 chains.
5	S 48½° E	1.59 chains.
6	S 14¼° E	1.14 chains.
7	S 19½° E	2.15 chains.
8	S 23½ W	1.22 chains.
9	S 5° W	1.40 chains.
10	S 30° W	1.02 chains.
11	S 81½° W	0.69 chains.
12	N 32½° W	1.98 chains.

Find area by double longitudes.

Ans. 1 A. 1 R. 27¾ P.

(748) In laying out town sites, what matters should first be considered?

(749) (*a*) How should the grades of streets be arranged with reference to drainage? (*b*) with reference to topography?

(750) How should *base lines* be located with reference to railroad lines?

(751) What is the usual order of preliminary survey?

(752) How are measurements to be made?

(753) Give a brief sketch illustrating the mode of laying out *base lines* and *subdivisions*.

(754) How are *base lines* rendered permanent?

(755) What important requirement is met by locating street corners by intersecting lines?

RAILROAD LOCATION.

(ARTS. 1391–1452.)

(756) What is the first duty of the chief engineer ?

(757) What are terminals ?

(758) From what sources does the engineer gain information of the section of country to be operated in ?

(759) What is the prime object in building a railroad ?

(760) What is your idea of the distinction between matters which are financially important and those which are physically important ?

(761) What is the average continuous cut and fill, with proportionate amount of masonry that will equal the cost of the superstructure, i. e., ties, rails and fastenings, and ballast ?

(762) What are the main sources of traffic, and what measures should be taken to reach them ?

(763) What knowledge will enable the engineer to properly estimate the comparative cost of different lines ?

(764) Ordinarily, how many different routes will it be necessary for the engineer to examine, and what are the considerations which narrow the field of operations ?

(765) Define a *reconnaissance*, and its relative importance to other departments in the work of location.

(766) What assistance will the engineer require in making the reconnaissance ? How will he conduct the same, and what range of country should he cover ?

(767) Of what use is the hand level ?

(768) What records should be kept? What do the sizes and rate of current of different streams indicate?

(769) Give examples of the deceptive appearance of country, and state how the eye tends to exaggerate offsets, angles, and distances.

(770) In general, how should local reports and estimates of country be regarded?

(771) Are conditions often met where but one line is possible?

(772) What advantages do valleys possess over ridges or rolling country?

(773) What is the organization of a location party? what the necessary outfit?

(774) Under what conditions should the compass be used?

(775) How is the starting point usually determined with reference to other fixed lines or boundaries?

(776) Describe the order of conducting the preliminary survey.

(777) Describe the work of the level and topographical parties.

(778) What constitutes the office work of the preliminary survey?

(779) Define spur lines.

(780) Define a gradient, and state what considerations modify or determine gradients.

(781) What conditions limit curvature, and what latitude should the engineer be allowed in their use?

(782) What are *temporary lines*, and when and where may they be used to advantage?

(783) What is a paper location?

(784) Describe how field notes are made up from the paper location.

(785) What is a paper location profile?

(786) What constitutes the location party?

(787) A curve whose intersection angle is 32° 30′ is run in, and it is found that its tangent is parallel to the required tangent, but 26 ft. outside of it. How far backward must the P. C. be moved in order that the tangent may take its proper position ? Ans. 48.39 ft.

(788) If the intersection angle is 41° 20′ and the following tangent is parallel, but falls 13.4 ft. within the required tangent, how far forward must we move the P. C. ?
Ans. 20.29 ft.

(789) A compound curve in which the first curve is 6° and the second curve 9°, with an intersection angle of 34° 20′, terminates in a tangent parallel to but 26.4 ft. without a given required tangent; how far backward must the P. C. C. be moved in order that the tangent may take the prescribed position ? Ans. 128.33 ft.

(790) A compound curve in which the first curve is 3° and the second curve 7°, with an intersection angle of 36° 40′, terminates in a tangent parallel to but 32.4 ft. within a given required tangent; how far forward must the P. C. C. be moved in order that the tangent may take the prescribed position ? Ans. 98.33 ft.

(791) A compound curve in which the first curve is 4° and the second curve 6°, with an intersection angle of 37° 10′. terminates in a tangent parallel to but 56 ft. without a given required tangent; how far backward must the P. C. C. be moved in order that the tangent may take its required position ? Ans. 250.4 ft.

(792) A compound curve in which the first curve is 8° and the second curve 3°, with an intersection angle of 28° 40′, terminates in a tangent parallel to but 25.4 ft. without the required tangent; how far forward must the P. C. C. be moved in order that the tangent may take its proper position ? Ans. 33.33 ft.

(793) A compound curve in which the first curve is 9° and the second 4°, with an intersection angle of 36° 15′, terminates in a tangent parallel to but 33 ft. within the

required tangent; how far backward must we move the P.C.C. in order that the tangent may take its required position?

Ans. 42.78 ft.

(794) The P. C. and P. T. of a 7° curve having been established, it is found that obstacles lie in the path of the curve, and it is decided to run a parallel curve 100 feet within the 7° curve from which the stations on the required curve may be located; what will be the length of each chord corresponding to full stations on the required 7° curve?

Ans. 87.79 ft.

(795) Two angles of intersection are 34° 20′ and 41° 30; the distance between the points of intersection is 1,011 feet; what is the radius of the easiest reverse curve which will unite the given tangents?

Ans. Radius = 1,469.94 ft. = 3° 53.9′ curve.

(796) Two angles of intersection are 20° 14′ and 41° 08′; the distance between points of intersection is 816 feet; what is the radius of the easiest reverse curve which will unite the tangent? Ans. Radius = 1,473.88 ft. = 3° 53.3′ curve.

(797) The angle *E B C* in Fig. 17 = 28° 40′, the angle *F C B* = 30° 16′, and the line *B C* = 470 ft.; required, the

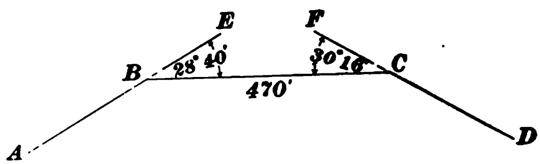


FIG. 17.

radius of the curve which will be tangent to the lines *A B*, *B C*, and *C D*. Ans. Radius ≐ 893.6 ft. = 6° 24.7′ curve.

(798) In Fig. 17 let the angle *E B C* = 32° 50′, the angle *F C B* = 41° 20′, and the side *B C* = 516 ft.; required, the radius of the curve tangent to *A B*, *B C*, and *C D*.

Ans. Radius = 768.05 ft. = 7° 27.6′ curve.

(799) A preliminary line crosses a wide stream, and a plug is set on line on both sides of the river. The transit is set over one plug, and an angle of 1° is then turned from the

line of survey and a plug set directly opposite to the plug on the other side of the stream. If the distance between these plugs is 7.3 ft., what is the width of the river ?

Ans. 418.3 ft.

(800) What opportunity does clearing the right of way afford for bettering the line ?

(801) How are transit points referenced, and what is the object of referencing them ?

(802) When are final levels taken ? Of what are they the basis ?

(803) What is the principal effect of curvature upon passing trains ? What are the usual compensations for curvature ?

(804) The location notes between Stations 20 and 40 are as follows :

Stations.	Intersection Angles.	Elevation of Grades.
40		142.50
36 + 30 P. T.		137.6271
31 + 80 P. C. 8° L.	36° 00′	132.7806
28 + 70 P. T.		128.6979
24 + 50 P. C. 10° R.	42° 00′	124.4265
20		118.50

Assuming that the elevation of grade of Sta. 20 is 118.50 ft., and the elevation of grade at Sta. 40 is 142.50 ft., and allowing a compensation of .03 ft. per degree, what are the grades for the tangents and curves, and what are the elevations of grade at the points of curve and tangent on the given line ? Explain the process by which the rates of grade and elevations are determined.

(805) When are vertical curves employed, and what is their object ?

(806) Two grade lines, the first an ascending grade of 1 per cent., and the second a descending grade of 0.8 per cent., are to be united by a parabolic vertical curve of a length of 600 ft. What is the value of a; and if the elevation of the beginning of the curve on the ascending grade is 110 ft., what are the elevations of the grades for the remaining stations of the curve, the starting point of the curve being Sta. 0, and the remaining stations being numbered in regular notation?

$$\text{Ans.}\begin{cases} a = 0.15 \text{ ft.} \\ \text{Grade at Sta. } 0 = 110 \text{ ft.} \\ \text{Grade at Sta. } 1 = 110.85 \text{ ft.} \\ \text{Grade at Sta. } 2 = 111.4 \text{ ft.} \\ \text{Grade at Sta. } 3 = 111.65 \text{ ft.} \\ \text{Grade at Sta. } 4 = 111.6 \text{ ft.} \\ \text{Grade at Sta. } 5 = 111.25 \text{ ft.} \\ \text{Grade at Sta. } 6 = 110.6 \text{ ft.} \end{cases}$$

(807) Draw a figure showing the grade lines specified in the previous question, and the vertical curve required to unite them.

(808) What is the usual classification of materials to be handled or used in the work of construction?

(809) What are the usual slopes given to earth cuts, rock cuts, and embankments?

(810) How is the line divided before construction is commenced, and what are the divisions called?

(811) What is the standard width of right of way?

(812) In advertising work for contract, what important reservation should the company make?

RAILROAD CONSTRUCTION.

(ARTS. 1453–1502.)

(813) When a line of railroad is in readiness for construction, how is it subdivided?

(814) What are the duties of the division engineer?

(815) What are the slopes usually given in setting slope stakes for embankment and for excavation?

(816) The height of instrument is 127.4 feet, the elevation of grade is 140 feet, and the rod reading for the right slope is 9.2 feet; what is the fill and the distance of the right slope stake from the center line, the roadway being 16 feet in width?

Ans. { Fill, 21.8 feet.
Side distance, 40.7 feet.

(817) The height of instrument is 96.4 feet, the grade 78.0 feet, the rod reading at the center line is 4.7 feet; what is the amount of cutting? Ans. 13.7 feet.

(818) With the same height of instrument and grade as in question 5 and a left rod reading of 8.8 feet, what is the cutting and the side distance, the width of roadway being 18 feet?

Ans. { Cut, 9.6 feet.
Side distance, 18.6 feet.

(819) How should the operation of clearing be conducted?

(820) Describe the modern mode of grubbing stumps.

(821) Name the different classes of culverts.

(822) With a coefficient of 1.8 and a drainage area of 400 acres, what should be the area in square feet of a culvert opening? Ans. 36 square feet.

(823) An embankment is 28 feet in height; a box culvert with an opening 3 feet wide and 4 feet in height will pass the water. The covering flags are 1 foot thick, and the parapet 1 foot high. (*a*) What will be the distance from the center line to the face of the culvert? (*b*) What will be the distance from the face of the abutment to the end of the wing walls?

Ans. { From center to face of culvert, 44 ft. 4 in.
From face of abutment to end of wing wall, 9 ft. 6 in.

(824) What should be the limit of the span of a box culvert; and when a greater opening is required to pass the water, how is it obtained?

(825) What is the usual foundation for a box culvert, and how is it prepared?

(826) What are some of the means employed to obtain a secure foundation in soft or marshy soils?

(827) What are tile culverts; under what conditions are they ordinarily employed, and how are they built?

(828) How should cattle guards be built?

(829) The height of the embankment at an open passageway is 16 feet; what should be the thickness of the base of the wall directly below the center line? Ans. 6.4 ft.

(830) Name the different parts of an arch.

(831) Name the different classes of arches, and describe them.

(832) The radius of a semicircular arch of cut stone is 15 feet; what should be the depth of the keystone? Give depths by both Trautwine's and Rankine's formulas.

Ans. { By Trautwine's formula, depth of keystone = 1.57 ft.
By Rankine's formula, depth of keystone = 1.34 ft.

(833) The span of a segmental arch is 38 feet; the rise is 12 ft.; what is the length of the radius which will touch the soffit of the arch at the springing lines and crown?

Ans. 21.04 ft.

(834) The radius of an arch is 12 ft. and the rise 8 ft.;

what should be the thickness of the abutments at the spring line, providing their height is not more than 1½ times the width of their base? Ans. 5.2 ft.

(835) (*a*) What are the essential ingredients of concrete? (*b*) What are the usual proportions of the ingredients? (*c*) How should they be mixed?

(836) What is the object in making the foundation area greater than that required for the superstructure?

(837) What is the advantage of ramming concrete?

(838) What are suitable proportions of sand and cement for mortar to be used in arch culvert masonry, and how should the ingredients be mixed?

(839) What is the minimum tensile strength per square inch of neat cement of 24 hours' age allowable in arch culvert work?

(840) What is the object in pointing the joints of masonry? Describe the process.

(841) What are arch centers, their object, and how built?

(842) What are striking or lowering wedges, and what purpose do they serve?

(843) In laying arch stones, how should the beds be arranged?

(844) When should the backing of an arch be started?

(845) At what stage in the building of an arch is the pressure liable to lift the crown? When is the pressure liable to lift the haunches?

(846) At what angle to the faces of an arch culvert are wing walls usually built?

(847) What is a retaining wall?

(848) A retaining wall of mortar rubble 10 feet in height is required to sustain an embankment of earth level with its top; what should be the thickness of its base, the front being battered 1 inch to the foot and the back vertical?

Ans. 4 ft.

(849) How does inclining the base of a retaining wall backwards affect its stability?

(850) What effect is produced by battering the back of the wall?

(851) In latitudes where deep freezing occurs, what measures should be taken to withstand its effects?

(852) What produces the effect of bulging in retaining walls?

(853) Illustrate by figure the method of offsetting the backs of retaining walls so as to increase their base without increasing their volume.

(854) What are surcharged walls?

(855) Explain by figure the angle, the slope, and the prism of maximum pressure.

(856) In determining the dimensions of a retaining wall, what is the unit length of section of wall and backing used?

Ans. 1 ft.

(857) When the backing is level with the top of the wall, at what point of the back of the wall is the center of pressure?

(858) Give the formula for perpendicular pressure, with explanatory figure.

(859) What are the forces which give to a retaining wall its stability?

(860) What is meant by the angle of wall friction?

(861) The height *o d* (see Fig. 18) of the retaining wall *a b d c* is 16 ft. The thickness at the base *c d* is 8 ft.; the thickness at the top *a b* is 2.5 ft.; the front is battered 1 inch to the foot, and the base *b f* of the triangle *b d f* is 12.73 feet. Taking the weight of the backing at 120 pounds per cubic foot and the weight of the wall at 154 pounds per cubic foot, determine graphically to a scale of 4,000 lb. = 1 in. the resultant of the forces tending to overturn the wall about its toe *c* as a fulcrum.

(862) What does earth work embrace?

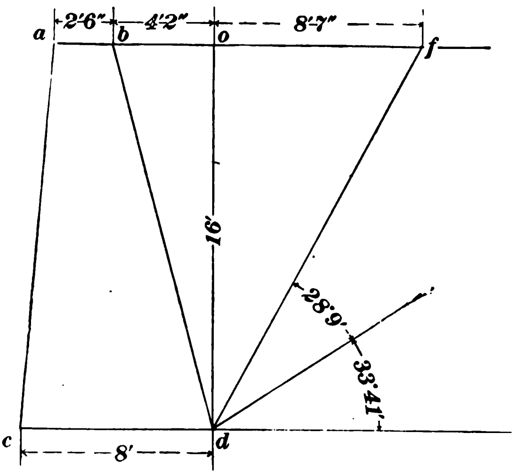


FIG. 18.

(863) Describe the different sections formed by the roadway.

(864) What character of work is best performed by a road machine ?

(865) What is meant by the term "lead"?

(866) With a lead of 400 feet and wages at $1.15 per day, what would be the cost per cubic yard to the contractor for delivering earth at the dump, the gang numbering 24 men, with foreman at $2.00 per day, water carrier at $0.90 per day, and allowing 1 pick to 5 wheelbarrows and ½ cent per yard for wear of tools and barrows ? Ans. 21.25 cents.

(867) With a lead of 700 feet and wages at $1.20 per day, what will be the cost per cubic yard to the contractor to deliver light sandy soil upon the dump, carts with driver costing $1.40 per day; foreman in charge of 12 carts, $2.25 per day; water carriers, $1.00 per day; dumping and spreading, 1 cent per cubic yard; number of minutes actually employed by shovelers, 420 per day; rate of travel for carts, 100 feet of lead per minute; time consumed in loading and turning and dumping, 4 minutes, allowing 2 cents per cubic yard

for loosening soil and $\frac{1}{2}$ cent per cubic yard for use and wear of tools ? Ans. 16.98 cents.

(868) Name the different methods of hand drilling.

(869) What special advantages have jumper drills over churn drills ?

(870) What are percussion drills ?

(871) In the percussion drill, how is the rotation of the drill effected ?

(872) What are the advantages of compressed air over steam for tunnel work ?

RAILROAD CONSTRUCTION.

(ARTS. 1503–1592.)

(873) At what depth of cutting does it become expedient to drive a tunnel?

(874) What is the most favorable time in the day for running tunnel lines, and what conditions of the atmosphere are necessary for accurate results?

(875) What is the object of running the line by foresights?

(876) What are the usual methods employed in measuring the surface line?

(877) Assuming 60° F. as normal temperature, what is the correct length of a line which measures 89.621 feet, the temperature being 94°? Ans. 89.641 ft.

(878) The distance between two points on a tunnel line as measured on the slope is 89.72 feet; the difference of elevation between the extremities is 11.44 feet; what is the horizontal distance between the extremities?

Ans. 88.986 ft.

(879) What are standard dimensions for a single track tunnel section? what for a double track?

(880) In tunnel driving, how is the section of the tunnel divided?

(881) Show by figure the arrangement of drill holes in the heading and bench.

(882) What is the usual order of firing the holes?

(883) What is the first consideration in determining tunnel grades? What rate of grade will insure complete drainage?

(884) What is the usual arrangement of tunnel tracks?

(885) The elevation of the grade of a station in a tunnel is 162.0 feet; the height of instrument is 179.3 feet; the height of the tunnel section is 24 feet; what should the rod read when the roof is at grade? Ans. 6.7 ft.

(886) In tunnel work, what special advantage is obtained by sinking shafts?

(887) Describe the usual arrangement of tunnel tracks and scaffolding for loading excavated material.

(888) Briefly describe the process of tunneling through soft ground.

(889) How is the center line of the tunnel run and maintained during construction?

(890) Describe the process of plumbing a shaft.

(891) How much pure air per minute does a man require in order that he may do effective work?

(892) An 18-inch air pipe conveys air from a tunnel heading at a velocity of 13 feet per second; how many laborers will it provide with pure air, allowing 100 cubic feet per man per minute? Ans. 14 laborers.

(893) What is an average day's work for a machine drill in lineal feet of hole drilled?

(894) What are surface ditches?

(895) What are cribs, and how are they used in protection work?

(896) Where is stone paving usually employed in works of protection?

(897) A culvert crosses a railroad line at an angle of 75°; the opening is three feet in height; the covering flags and the parapet each 1 foot in height, and the embankment 21 feet in height. What should be the distance from the center line to the face of the culvert? Ans. 36.06 ft.

(898) What are borrow pits?

(899) How should they be staked out?

(900) How should they be mapped and their contents calculated?

(901) What are grade stakes?

(902) The grade at a station is 118.7 ft.; the height of instrument is 125.5 ft.; what should the rod read at the station, for the roadway to be at grade? Ans. 6.8 ft.

(903) What does the term *overhaul* signify?

(904) What are the two important factors in the location of a bridge?

(905) What is the meaning of the term *skew* as applied to bridges?

(906) Describe a method of making a direct measurement of a bridge span?

(907) Let *A B* (see Fig. 19) be the center line of the proposed bridge, and *B C* the base line, the length of which is 421.532 ft. The angle *A* is 46° 55′; the angle *C* is 43° 22′; required, the length of *A B*.

Ans. 396.31 ft.

(908) What are some of the considerations which determine the number and location of the piers of a bridge?

(909) When the river bed is of rock, or firm sand, or clay, how are pier foundations prepared?

(910) What are cofferdams?

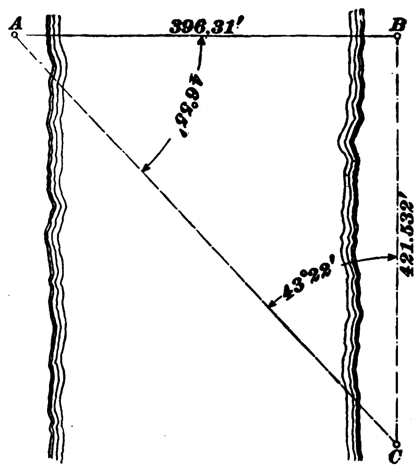


FIG. 19.

(911) A side of a cofferdam is 40 feet in length and 11 feet in height; the water is 10 feet in depth; (*a*) what is the total water pressure against the side of the dam? (*b*)

What is the moment of the water pressure about the inner tee of the dam? Ans. { (*a*) 125,000 lb. (*b*) 10,417 ft.-lb.

(912) If the filling of the dam is 5 feet in thickness, 11 feet in height, and weighs 130 lb. per cu. ft., (*a*) what is the moment of resistance of which the filling alone opposes to the water pressure? (*b*) What is the factor of safety of the dam? Ans. { (*a*) 17,875 ft.-lb. (*b*) 1.71.

(913) Under what conditions would you construct a pile foundation?

(914) How would you protect the foundation from the scour of the current?

(915) What stone is best suited to bridge foundations?

(916) In building bridge piers, what are the different materials used for backing?

(917) Under what conditions are pneumatic foundations employed?

(918) What are *test holes* as employed in foundation work, and how are they ordinarily made?

(919) Describe the construction and use of the sand pump.

(920) How does the depth of the foundation affect the size of the caisson?

(921) What is the object in battering the sides of a caisson?

(922) How is entrance to the caisson chamber effected?

(923) Explain the working of the air locks.

(924) How is the air pressure within the caisson utilized in removing the material excavated in sinking the caisson?

(925) How is the sinking of the caisson regulated?

(926) Describe the process of sealing the caisson.

(927) What is the air pressure in the caisson at a depth of 70 feet below the water surface?

Ans. 45.38 lb. per sq. in.

(928) Give the *Engineering News'* formula for pile driving.

(929) What are the various methods employed in pile driving ?

(930) A hammer weighing 3,500 pounds falls free from a height of 30 feet upon the head of a pile; what is the force of the blow ? Ans. 105,000 ft.-lb.

(931) When driving a pile, what is the effect of an interval of rest between blows ?

(932) What effect have broomed pile heads upon the striking force of the hammer ?

(933) What effect results from driving piles with hammer rope slackened on the drum ?

(934) Describe pile shoes and hoops, and state their object.

(935) What are some of the effects of overdriving piles? What is the safe limit in spacing bearing piles ? What are the effects of overcrowding ?

(936) A hammer weighing 3,000 pounds falls from a height of 22 feet; the average penetration of the last three blows is $\frac{1}{2}$ inch; what is the safe load in tons which the pile will support ? Ans. 44 tons.

(937) A trestle bent contains three piles. In driving them a hammer weighing 3,300 pounds, falling from a height of 35 feet, produces the following last penetrations, viz., first pile, $\frac{3}{4}$ inch; second pile, $\frac{4}{5}$ inch; third pile, $\frac{7}{8}$ inch; required, the total safe load of the bent in tons.

Ans. 191.77 tons.

(938) Into what two general classes are pile-driving machines divided ?

(939) What are the essential parts of a pile-driving machine ?

(940) What are sheet piles ?

(941) What is the prismoidal formula, and what application is made of it in estimating earth work ?

(942) Describe the quantity book.

(943) What are monthly estimates; when are they made, and how do they reach the chief engineer?

(944) What are temporary allowances?

(945) What percentage of the estimate is usually reserved by the company, and what is the object of such a reservation?

(946) What is the final estimate?

TRACK WORK.

(ARTS. 1593–1727.)

(947) What constitutes a good track?

(948) Why is a hewn tie superior to a sawed tie?

(949) Name the months most favorable for cutting tie timber.

(950) (*a*) What are proper dimensions for standard gauge cross-ties? (*b*) Where should they be piled for inspection, and what are the usual marks employed by a tie inspector?

(951) (*a*) At what interval should track centers be placed? (*b*) At what intervals should stakes for bedding ties be placed?

(952) What is an average day's work in track laying with a machine?

(953) (*a*) How are ties lined? (*b*) how bedded?

(954) Define suspended and supported joints.

(955) Describe the proper method of transferring rails from car to car, and of delivering them from the car to the grade.

(956) How may kinked rails be straightened?

(957) A curve contains 42°; how many 29½-ft. rails are required to keep the joints in proper position?

Ans. 7 rails.

(958) At a temperature of 85°, an iron bar measures 30.016 feet; assuming normal temperature at 60°, what is the normal length of the bar? Ans. 30.011 ft.

(959) What are expansion shims, and their objects?

(960) What is the proper mode of driving spikes, and how should they be arranged in the tie?

(961) What is the proper mode of gauging track?

(962) Describe the process of lining track.

(963) After a new track is laid, what are the steps taken to put it into surface?

(964) What is subgrade?

(965) State some of the methods for effecting the drainage of cuttings.

(966) Give sketch showing section of track in earth ballast and in rock ballast.

(967) What is the effect of straining track bolts?

(968) Describe the process of putting new ties into a track.

(969) How is old track prepared for ballasting with stone or gravel?

(970) What is the proper method to be employed in raising track?

(971) What is the most effective form of fence for fencing a railroad?

(972) What height of fence is prescribed by law in most of the States?

(973) What are shims?

(974) What effect has frost upon pile bridges?

(975) How are snow drifts prepared for the snow plow?

(976) Where are snow fences required, and how located?

(977) An 8° curve is 425 feet in length, the gauge of track is 4 feet 9 inches, the width of the rail head, 2 inches; what is the excess of length of the outer rail over the inner rail? Ans. 2.91 ft.

(978) What is the middle ordinate of a 30-foot rail for a 6° curve? Ans. $1\frac{1}{2}$ in.

(979) The middle ordinate of a 50-foot chord is $3\frac{1}{2}$ inches; what is the degree of the curve? Ans. 5° 36′.

(980) Why is it necessary to widen the gauge on sharp curves?

(981) What is the proper method of lining curves?

(982) What is the formula for curve elevation?

(983) A curve is 10°, and the velocity of train is 35 miles per hour; by the formulas $c = 1.587\,V$ and $m = \frac{c^2}{8R}$, what should be the elevation of the outer rail of the curve?

Ans. 8 in., nearly.

(984) If the elevation of the outer rail of a curve is 4 inches, what should be the length of the elevated approach?

Ans. 240 ft.

(985) What is the object of *coning* the treads of car wheels?

(986) What is a turnout?

(987) What do you understand by the number of a frog?

(988) Name the two classes of frogs, and describe them.

(989) What are crossing frogs?

(990) What is a replacing frog, and how is it used?

(991) Name the two principal types of switches.

(992) Describe the stub switch.

(993) Describe the split switch.

(994) (*a*) What is a facing switch? (*b*) a trailing switch?

(995) What is a safety switch?

(996) What is a three-throw switch?

(997) What are derailing switches?

(998) What are automatic turnouts?

(999) What is a **Y** track?

(1000) The radius of the turnout curve from a straight track is 602.8 feet, and the gauge is 4 feet 8½ inches; what is the frog number?

Ans. No. 8 frog.

(1001) In a turnout from a straight track, the number of the frog is 6, the gauge of the track is 4 feet 8½ inches; what is the radius?

Ans. 339 ft. = 16° 54′ curve.

(1002) The degree of the turnout curve from the straight track is 18°, the gauge is 4 feet 9 inches; what is the frog distance and frog angle?

Ans. { Frog distance = 55.1 ft.
Frog angle = 9° 55′.

(1003) The main track is a 6° curve, and to reach a certain warehouse it is necessary to use a 10° 30′ curve in the opposite direction from that of the main track; what is the required frog distance and frog angle, the gauge at the track being widened to 4 feet 9 inches?

Ans. { Frog distance = 57.5 ft.
Frog angle = 9° 29¼′.

(1004) The main track is a 4° curve to the right, and to reach a certain point it is necessary to put in a 12° turnout curve to the right; how far from the P. C. of the turnout curve shall we place the head block, if we allow 5 inches between the gauge lines, the gauge being widened to 4 feet 9 inches? Ans. 24.5 ft.

(1005) If the spread of the heel of a No. 9 frog is 8½ inches, what is the distance from the heel to the theoretical point of frog? Ans. 6 ft. 4½ in.

(1006) At what distance from the gauge line should a guard rail be placed, when the track is laid to a close gauge? Ans. 1⅞ in.

(1007) The distance from the head block of a switch to the last long tie behind the frog is 60 feet; the ties being 15 inches apart, how many switch ties are required for the switch? Ans. 48.

(1008) The length of the tie next the head block is 8 feet 6 inches, the length of the last long tie behind the frog is 15 feet 3 inches, the number of switch ties is 48; what is the amount to be added to the length of each tie to give the length of the next? Ans. 1$\frac{1}{16}$ in.

(1009) How do you obtain the length of switch timbers for a three-throw switch?

(1010) A three-throw switch is formed by two turnout

curves at 10° each; what is the angle of the crotch frog, the gauge being 4 feet $8\frac{1}{2}$ inches? Ans. 10° 22.8′.

(1011) What are cross-over tracks?

(1012) What is the proper method of lining detached track?

(1013) When cutting steel rails, what precautions should be taken?

(1014) At what distance from the point of danger should danger signals be placed?

(1015) At what distance from stations should whistling posts be located?

(1016) When repairing track, what precautions should be taken to protect trains?

RAILROAD STRUCTURES.

(ARTS. 1728–1824.)

(1017) What is the average life of a wooden trestle?

(1018) Why are mathematical formulas less reliable for designing structures of wood than structures of metal?

(1019) What should be the limit in height for a pile trestle?

(1020) What advantage is derived from piles driven at a batter?

(1021) Under what conditions may a 3-pile bent be employed?

(1022) What conditions require the splicing of piles?

(1023) Before ordering the material for a pile bridge, what measures should be taken to determine the necessary length of piles required?

(1024) Name the different methods of fastening caps to piles.

(1025) (*a*) What is the standard size of mortise and tenon for post, cap, and sill connections? (*b*) What are treenails?

(1026) What are the special merits of *split caps?*

(1027) What advantages, besides stability, result from proper foundations for trestles?

(1028) Name the several kinds of foundations employed in trestle building.

(1029) Under what conditions would you employ a grillage foundation?

(1030) How are crib foundations constructed, and to what situations are they best suited?

(1031) How are foundations of broken stone prepared?

(1032) What are drip holes, and what purpose do they serve?

(1033) What are corbels, and their object?

(1034) What are separators, and their object?

(1035) What are packing-blocks, and their object?

(1036) What two methods are commonly adopted to fasten stringers to caps?

(1037) What are spreaders?

(1038) What are the safe standard dimensions for stringers for standard trestles?

(1039) What are jack-stringers, and their object?

(1040) (*a*) At what distance apart should trestle ties be spaced? (*b*) What advantage results from placing them close together?

(1041) What advantage results from notching down the ties over the stringers?

(1042) What are guard-rails, their object, and how are they fastened to the ties?

(1043) How are guard-rails spliced?

(1044) What modification should be made in the form of the guard rail at the connection of the trestle with the embankment?

(1045) What are sway-braces, and their object?

(1046) How is the elevation of the outer rail effected on curved trestles?

(1047) Which form of drift-bolts has the greater holding power, round ones or square ones?

(1048) In what two ways are trestles commonly connected with embankments?

(1049) Name some devices for protecting trestles against fire.

(1050) Describe the usual method of erecting trestles.

(1051) What is the principal object of numbering bridges?

(1052) In building pile trestles, what is the object of notching the caps over the piles?

(1053) A spruce beam is 10 inches broad, 12 inches deep, and 18 feet long; what is its center breaking load?

Ans. 36,000 lb.

(1054) When beams are inclined, what constitutes the span?

(1055) A square horizontal beam of yellow pine is 20 feet in length between supports; what should be its dimensions to break under a quiescent center load of 50,000 pounds?

Ans. $12\frac{3}{8}$ in. square, nearly.

(1056) A beam having a span of 16 feet must safely bear a center load of 16,000 pounds; what should be the side of a square beam of yellow pine to carry this center load with a factor of safety of 5? Ans. $13\frac{1}{4}$ in.

(1057) A horizontal rectangular beam of spruce is 12 inches in depth and 14 feet between supports; what should be its breadth to break under a quiescent center load of 40,000 pounds? Ans. $8\frac{5}{8}$ in.

(1058) A horizontal rectangular beam of yellow pine is 10 inches broad; the distance between supports is 16 feet; what should be the depth of the beam to break under a quiescent center load of 24,000 pounds? Ans. $8\frac{3}{8}$ in.

(1059) A rectangular pillar of yellow pine is 12 in. $\times$ 12 in. in section, and 12 feet high; what is its safe load with a factor of safety of 5? Ans. 91,296 lb.

(1060) A beam of long-leaf yellow pine is subjected to a shearing stress of 30,000 pounds across the grain; how many square inches of timber are required to resist this stress? Ans. 60 sq. in.

(1061) A beam of white oak is subjected to a shearing stress across the grain of 40,000 pounds; how many square inches of timber are required to sustain it? Ans. 40 sq. in.

(1062) What should be the side of a square horizontal beam of spruce which must support, with a factor of safety of 4, a uniformly distributed transverse load of 36,000 pounds, and a pull of 20,000 pounds, the distance between the supports being 12 feet? Ans. 12.6 in.

(1063) What is a king-rod truss?

(1064) A bridge of 20 feet span, and carrying an equivalent live and dead load of 6,000 pounds per lineal foot, is carried by king-rod trusses; what is (*a*) the load upon each king-rod, and (*b*) what should be the diameter of each, using a factor of safety of 6? Ans. (*b*) $2\frac{3}{8}''$.

(1065) If the truss described in the preceding example carries a needle-beam supporting the floor-beams, what share of the total load will the needle-beam support?

(1066) What advantage is gained by trussing the needle-beam?

(1067) What is a queen-rod truss?

(1068) A load of 20,000 pounds travels from both ends of the straining beam of a queen-rod truss towards the center; what is the total stress in the beam?

(1069) A queen truss is 33 feet in length between supports. The combined live and dead load is equivalent to 6,000 pounds per lineal foot of bridge. The queen-rods divide the bridge into three equal parts; what is the stress upon each rod? Ans. 33,000 lb.

(1070) What are water stations?

(1071) What is their ordinary capacity?

(1072) What precautions should be taken against drouth or impurities in water due to floods?

(1073) What advantage is gained from an elevated water supply?

(1074) What is the usual capacity of locomotive tender tanks?

(1075) What advantage have the individual stone pediments for posts over wooden sills carried by continuous walls?

(1076) What is a water column ?

(1077) What advantage does the water column offer in its adaptation for yard supply ?

(1078) What are coaling stations ?

(1079) What application is made of the link belt in modern coaling stations ?

(1080) What is a turntable ?

(1081) What is the proper location for a tool house, and what are its essential requirements ?

(1082) What are the essential requirements of a section house ?

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